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POSTATTACK FARM PROBLEMS

PART II: ATTACK EFFECTS ON INPUTS AND FARM OUTPUT

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FOREWORD

This study was conducted under contracts CDM-SR-59-19 and CDM-SR-60-37 for the Office of Civil and Defense Mobilization (now the Office of Emergency Planning). The work, a part of the Systems Analysis studies being conducted for OEP, was performed in the Management Sciences Division. This report is the second of two devoted to the possible effects of nuclear attacks on U.S. farm production; it deals with the postattack availability of critical farm inputs and uses the production model devised in the first report (Part I) to estimate total postattack agricultural production.

Program direction was provided by Rogers S. Cannell, Director of the Emergency Planning Research Center, and George D. Hopkins, Manager, Operations Analysis Group. Kendall D. Moll served as project leader of the farm production study. Oliver E. Williamson was the major author of this report. William Bowman and Clair Lee designed the illustrations. Dot maps of agricultural resources from the 1954 Census of Agriculture were used where appropriate.

Detailed comments on the original draft of this report were made by Dr. Earl O. Heady of the Center for Agricultural and Economic Adjustment, Iowa State University; and Dr. Frank Meissner, Division of Business, San Francisco State College; as well as S. A. Cogswell, Neil T. Houston, R. Hal Mason, Richard R. Tarrice, and others of the Stanford Research Institute staff. The draft was also circulated for review by interested officials in OEP and the Department of Agriculture.

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SUMMARY

The major finding of this report is that farm food production in the first year after a nuclear attack might be less than demands of the surviving population unless several major adaptations were made. With mobilization measures such as conversion of croplands from non-food and livestock feed production to human food production and use of surplus commodity stocks for livestock feed, adequate production could probably be maintained. Food production would increase in subsequent years unless national recovery were prevented by continued unsettled conditions.

Contamination of cropland and losses of livestock would probably be the most serious constraints to agricultural production for the first postattack year. However, if fallout effects on cropland and livestock were less serious than currently estimated, casualties among farmers could be the chief constraint. In any event, production would probably be limited primarily by one of these constraints, rather than by the cumulative effects of less critical inputs. Estimates of production for a range of assumptions about human, animal, and crop vulnerabilities to attack are given in Chapters XII and XIII.

Other findings are:

1. Land and livestock would be adequately available following attacks possible in the early 1960's, but could be significantly depleted following heavier attacks assumed to be possible in the late 1960's. (Chapter III)

2. Farm manpower would be available in the postattack period if shelters equivalent to an ordinary home basement were used for protection from fallout. Extra manpower may even be available for diversion to other sectors of the economy. (Chapter IV)

3. Gasoline storage in rural bulk tanks and on farms is about equal to a normal two- to three-month supply. This stored supply, together with postattack gasoline production, would probably be adequate to keep the agricultural system functioning during the first postattack year, unless gasoline were diverted from farming to military or other purposes. (Chapter V)

4. Farm equipment should be available in entirely sufficient amounts for the first postattack year. (Chapter VI)

5. Although losses of electric power generation are estimated to be large following attacks on population targets, the flexibility inherent in rural power transmission should permit the relatively small farm requirement to be nearly satisfied. (Chapter VII)

6. Irrigation water should be generally available in required amounts postattack. (Chapter VIII)

7. Supplies of all soil nutrients would be adequate following hypothetical light attacks in the early 1960's, with the exception of triple superphosphate. After heavier attacks in the late 1960's, manure, triple superphosphate, and potash would be in severe short supply, but sulfur, calcium, and magnesium would be fully available, and limited amounts of nitrogen and normal superphosphate might be available. (Chapter IX)

8. Production of pesticides involves a series of chemical processing operations often conducted at different locations throughout the country; this feature makes pesticides particularly vulnerable following attacks directed at population targets. (Chapter X)

9. Seed supplies on the farm and normal dealer and government seed inventories should assure adequate amounts of most types of seed. (Chapter XI)

10. Unless major postattack adjustments were made to the farm economy, agricultural output (on a monetary value basis) would amount to less than 50 percent of requirements for the surviving population after hypothetical heavy attacks in the late 1960's. The degree of fallout protection would not greatly affect the balance of food production and population requirements, since both would be increased by better protection. (Chapter XII)

11. Surplus food in the government stockpile could, if processed and distributed, provide enough food value to meet requirements for many months under any attack conditions. Other emergency measures could be taken to provide additional food, such as diversion of food grains from animal use to direct population consumption and more intensive cultivation of existing and reserve agricultural land. Active but relatively small preattack planning and organizational efforts would be required to assure that such measures were implemented. (Chapter XIII)

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MANPOWER

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EQUIPMENT

ELECTRIC POWER

IRRIGATION WATER

SOIL NUTRIENTS

    Manure

    Nitrogen

    Phosphate

    Potash

    Liming Materials

PESTICIDES

SEEDS

Chapter I

INTRODUCTION

Background

It has been estimated that, at the end of 1918, the German people were consuming only sixty-four percent of the cereals, eighteen percent of the meat, and twelve percent of the fats that they had consumed before the war. When the war was over, German propagandists put the blame on 'the hunger blockade', and found gullible audiences both at home and abroad. The blame would have been more justly put upon the German Government. Before the war, the Germans were importing less than ten percent of their food. Their losses of overseas food imports were a small thing in comparison with the losses they inflicted on themselves by their failure to maintain home production. That failure had simple causes: decline in the number of draught animals and no compensating mechanisation of agriculture; inadequate production of fertilisers; insufficiency of farm labour. Each of these causes has its root in a deeper cause, the faulty balance of a war economy in which resources essential for maintaining the efficiency of the civilian population were engulfed by the armed forces and the industries most closely connected with them.[1]

In World War I Germany, as in many other historical instances, food production proved to be a weak link in national security. To aid in understanding the importance of food to present United States security, this study examines potential production of food on U.S. farms in a nuclear attack environment. In order to carry out the study, it has been necessary to deal successively with two questions: First, what input resources are required for food production, and second, how might these input resources (and resultant food production) be affected by a nuclear attack.

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[1] Hancock, W. K., and M. M. Gowing, British War Economy, History of the Second World War Series, pages 19 & 20, H. M. Stationery Office, London, 1949.

The first of these questions was analyzed in the Part I report of this study,[1] and the second is the subject of the present report. Together the two reports are intended to provide initial conclusions regarding civil defense problems of agriculture in the United States. Certain other studies by Stanford Research Institute and others have examined postattack problems in food processing, distribution, and allocation, as well as the over-all postattack food supply-demand balance. The findings of those studies were discussed in the Part I report. However, the complexity of the over-all food system required that the present study be limited to a detailed examination of farm production only. Similar complexities and uncertainties in the potential recuperation of farming required that the time frame of the study be limited primarily to the first postattack year. Detailed conclusions about postattack input resources are consequently limited in scope, and conclusions about input requirements or priorities for farm use are not attempted.

Nevertheless, this study has helped to prove a previously undocumented assumption of all vulnerability analyses: that effects of losses of a few of the more constraining inputs are dominant, and the cumulative effects of losses to less critical inputs have only a secondary influence on productivity. (For example, in farming, the cumulative effects of attack losses to electricity, commercial seed supplies, fertilizers, etc. are small compared with the effects of losses of land, farmers, or fuel.) It is therefore hoped that the methods of analysis and general conclusions developed in the present study can be profitably applied to a broad range of problems of resources and requirements, both for agriculture and for other industries.

Basic data for estimating attack losses in this report were obtained from unclassified portions of the Attack Damage Digest.[2] The relationship of the current report to the findings of the Part I report and to the Attack Damage Digest are discussed in the following chapter. For those readers who may desire a summary of the findings that are relevant to the present report, the following resumés are provided.

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[1] Kendall D. Moll, Jack H. Cline, and Paul D. Marr, Postattack Farm Problems, Part I: The Influence of Major Inputs on Farm Production, Stanford Research Institute, Menlo Park, California, December 1960.

[2] Attack Damage Digest, Stanford Research Institute, December 1959, revised April 1961. SECRET, RESTRICTED DATA. (All references to the Attack Damage Digest in this report are from unclassified portions of the study.)

Summary of Part I Report: The Influence of Major Inputs on Farm Production

The Part I report deals with effects on productivity of shortages in major resource inputs, such as fertilizers and commercial seeds, which are obtained off the farm. It does not consider the effects of losses of farms or farmland.

The findings of the Part I report are that shortages of inputs could result in serious declines in agricultural productivity but that effective actions could be taken to limit these declines. In the first year after a cutoff of all off-farm inputs, production under current methods would amount to less than one-third of normal. If inputs were not resumed after the first year, production would fall to lower levels because of the exhaustion of reserve supplies and the cumulative effects of continuing shortages. However, the adoption of a series of emergency measures could maintain productivity at about two-thirds of normal in the first postattack year even under extreme shortage conditions and could considerably reduce the effects of shortages in succeeding years.

The effects of shortages of inputs are estimated individually below. For these cases, the shortage is assumed to exist in only the one input under consideration (unless otherwise noted).

1. Fuel is the most critical off-farm input because of the extensive mechanization of modern U.S. agriculture. A 50-percent shortage of farm fuel supplies would limit agricultural productivity to about 74 percent of normal. Under current mechanized farming conditions, extra labor to supplant machinery would be of little value. A doubled labor input would increase production by only about 6 percent of normal.

2. Shortages of electricity would be most serious in livestock enterprises such as dairies and brooder operations. Electricity is also essential in many irrigated areas. A complete loss of electrical power would result in an over-all farm productivity drop to about 76 percent of normal.

3. Commercial fertilizers are particularly important to intensively farmed crops such as sugar beets, potatoes, and corn. Without fertilizers, national agricultural productivity would decline to 81 percent of normal in the first year, and to even lower levels in later years.

4. Pesticides are increasingly used to improve the production of many crops. Pesticide losses would reduce production in the first year to about 84 percent of normal, and the decline would become more serious over time.

5. Commercial seed supplies are necessary for some crops, but for many important crops, such as wheat, farmers replace seed supplies from previous crops. Over-all agricultural productivity would be reduced to about 86 percent of normal by a cutoff of commercial seed supplies.

6. Most farming areas have enough agricultural equipment, spare parts, and facilities to sustain production without serious replacement problems for several years. A loss of all outside sources of new equipment would limit productivity in the first year to 98 percent of normal.

Effective allocations of resources by agricultural authorities and individual farmers would be necessary to alleviate input shortages. Many changes in practices to increase the quantity of food could be made, particularly measures utilizing this country's great abundance of livestock feed in storage and in production. Stored feed stocks could be used either as livestock feed or human food, and feed crops produced after attack could be used efficiently as human food. Other adaptations of the farm economy, such as devoting more labor to farm and home food production, reverting to more primitive methods of raising livestock, and increasing the acreage in food crops would be of lesser but significant value.

Summary of Attack Conditions, from Attack Damage Digest

The input influences and adaptive measures in the Part I report are applied in the Part II report to postattack situations resulting from a series of four hypothetical attacks. The attacks, described in detail in the Attack Damage Digest, cover a range from minimum to maximum attack levels considered likely for the 1960 decade. The minimum-strength attacks would be most likely to occur very early in this period before a sizable Soviet nuclear strike force could be assembled and before a large number of U.S. retaliatory missile facilities are installed. Consequently the two minimal attacks are labeled "early 1960's" attacks. The maximum-strength attacks could occur only after a long build-up period of Soviet missile strength but before a really effective missile defense could be developed. Such attacks are assumed to be directed primarily at

ICBM bases in the western United States, which would also require a considerable construction period. The two maximal attacks are therefore labeled "late 1960's" attacks.

Within both the early and late 1960's periods, attacks are considered against military bases only ("military attacks") and against both military and population targets ("military-population attacks"). U.S. military bases capable of retaliation are assumed to be a primary aim of any nuclear attack on this country, but the objective of an enemy attack on U.S. population centers would be considerably less obvious. Therefore, population attacks are considered only as possible incremental objectives to the primary military aims.

The total megatonnages assumed to be delivered and the types of targets hit are shown in Figure 1. The attacks increase in size and change in orientation from the early to the late 1960's as a result of assumed increases in size and numbers of weapons, growth of cities, changes in our own defensive posture, and construction of U.S. missile bases. However, the estimates should not be regarded as predictions of actual attacks at actual times. They may be more fairly described as defining a range of damage that might be expected from a determined enemy attack during the present decade. Attacks resulting from an "accidental" war, or limited attacks involving a withholding of most of the potential attack force, could be much lighter than indicated.

Effects of the four assumed attacks were computed by the SRI Damage Assessment System,[1] and tabulated in the Attack Damage Digest. Physical damage and radioactive fallout coverages under each attack were estimated for such resources as population, food stocks, agricultural lands, industrial workers, and fuel and railroad facilities.

Objectives of the Part II Study

With estimates available from the above reports on the effects of input losses on agricultural productivity and on environmental effects of nuclear attack on the United States, the problem remaining for the

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[1] For a description of this system, see The Damage Assessment System, October 1957, prepared for Federal Civil Defense Administration by Stanford Research Institute.

FIG. I
TOTAL MEGATONS DELIVERED IN HYPOTHETICAL ATTACKS

THOUSANDS OF MEGATONS DELIVERED

0   5   10   15   20   25

EARLY 1960s MILITARY ATTACK — 400

EARLY 1960s MIL.-POP. ATTACK — 1500

LATE 1960s MILITARY ATTACK — 19,000

LATE 1960s MIL.-POP. ATTACK — 23,000

✈ BOMBER BASES

🚀 MISSILE BASES

👤 CITIES

⚓ NAVAL BASES

💉 AIR DEFENSE BASES

8
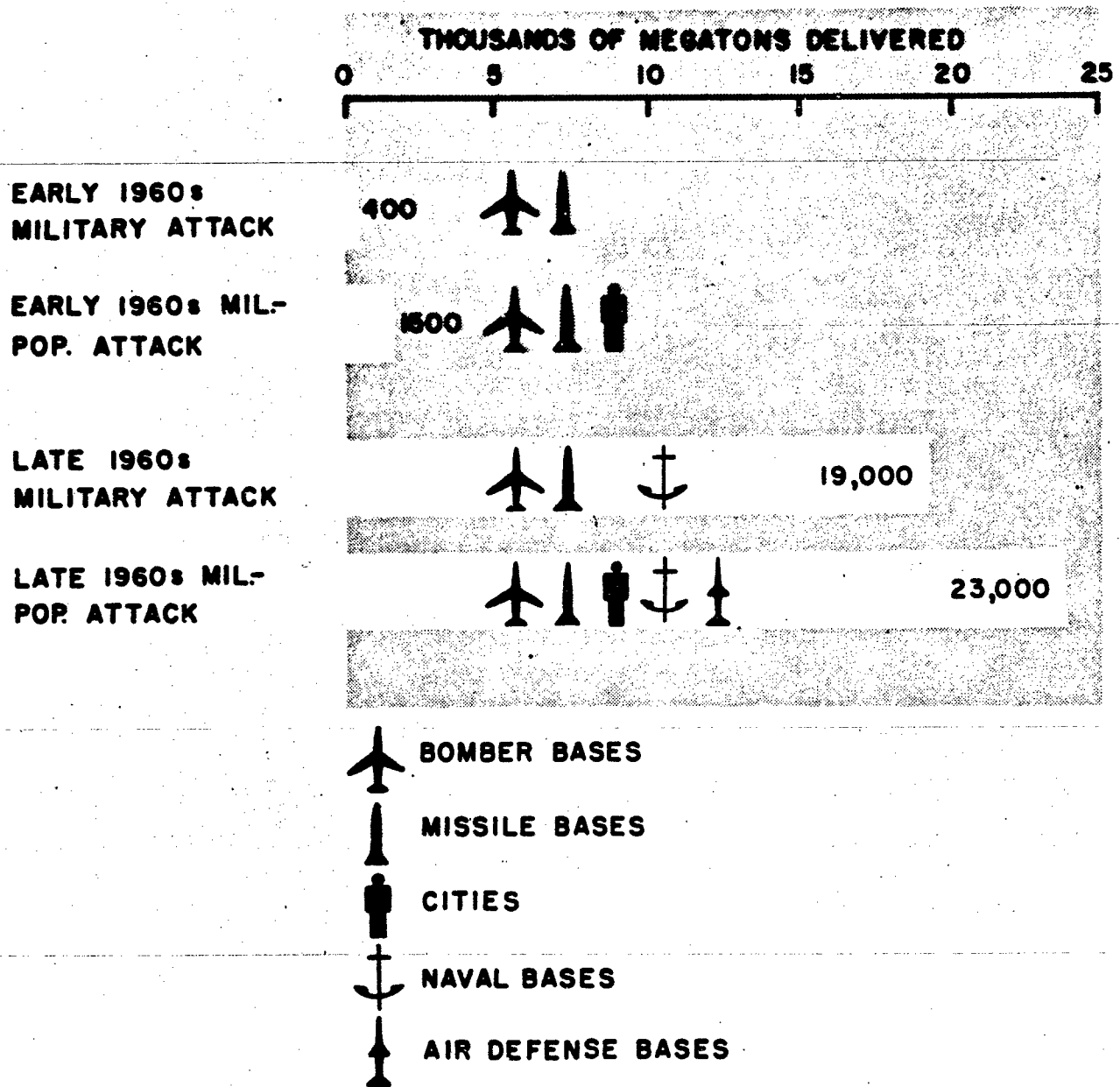
present report was to combine the estimates into an assessment of potential losses to agricultural production. Three basic objectives can be distinguished in the steps required to answer this problem:

1. To assess possible attack losses to each of the major inputs required by agriculture and to discuss the problems of re-establishing a normal supply of each.

2. To estimate the combined effects of losses of input resources on over-all productive capacity of agriculture in the first crop year after each of a range of possible nuclear attacks.

3. To indicate what adaptive measures would be most feasible for maintaining production of input resources and agricultural output.

METHOD OF ANALYSIS

PART I
INFLUENCE OF INPUTS

DESCRIBE FARM ECONOMY

SELECT SAMPLE PRODUCTS
WHEAT
...
...
CORN
...
MILK
...
...
HOMEGROWN FOODS

ESTIMATE EFFECTS OF IN-
PUTS ON SAMPLE PRODUCTS

COMBINE SAMPLE PRODUCTS

COMBINE INPUT EFFECTS

DERIVE OVERALL
PRODUCTIVITY OF INPUTS

CONSIDER CHANGES IN
FARM PRODUCTION

PART II
AVAILABILITY OF INPUTS

DESCRIBE INPUT SYSTEMS
LAND
MANPOWER
FUEL
EQUIPMENT
ELECTRICITY
IRRIGATION WATER
FERTILIZER
PESTICIDES
COMMERCIAL SEEDS

ESTIMATE
INPUT VULNERABILITY

CALCULATE OVERALL AGRI-
CULTURAL VULNERABILITY
CROPS
LIVESTOCK

CONSIDER CHANGES IN FARM
AND INPUT PRODUCTION

ATTACK DAMAGE DIGEST

RESOURCES DAMAGE
FROM 4 ATTACKS

EARLY 1960's
MILITARY
POPULATION
LATE 1960's
MILITARY
POPULATION

Chapter II

METHOD OF ANALYSIS

The relationship of the present report to the Part I repoit of this study and to the <u>Attack Damage Digest</u> is shown in the facing illustration. The present report describes the individual input systems that are important to farm production (land, manpower, fuel, etc.) and, using results from the prior reports, estimates their vulnerability to nuclear attack and the consequent loss of agricultural production.

Some of the analytical techniques and assumptions of the earlier reports were applied to work in the present report. Notably, models of the input production functions were adapted from the Part I report, and models of physical and fallout vulnerability to nuclear attack were adapted from the <u>Attack Damage Digest</u>. These models are described in detail below.

Agricultural Production Functions

Estimates of input availability can be converted to estimates of agricultural output if a production function (the relationship of input quantities to production output) is known. The general expression for such a function can be stated mathematically in the following terms:

$$Q = f\ (x_1,\ x_2,\ \ldots\ x_n)$$

where

$$Q = \text{aggregate output}$$

$$x_1,\ x_2,\ \ldots\ x_n = \text{amount of each input available}$$

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The problem is to reduce this general expression to a specific form that is both workable and useful. One function widely used by agricultural economists is of the Cobb-Douglas form:

$$Q = k\, x_1^{a_1}\, x_2^{a_2} \ldots x_n^{a_n}$$

where

Q = output

k = a positive constant

$x_1, x_2, \ldots x_n$ = amount of each input used in the production of Q

$a_1, a_2, \ldots a_n$ = the elasticity of production of each input

Most standard economic textbooks on price theory contain a discussion of some of the characteristics of this function, generally focusing on the elasticity relationships inherent in the function. This type of discussion will not be repeated here. Of greater interest is the fact that a multiplicative function of the above form assumes that the relative effects of a change of one input is independent of the amounts of other inputs. Also, for values of a less than 1, the Cobb-Douglas function shows diminishing returns for successive additions of any input.

However, since neither the Cobb-Douglas nor any other standard type of agricultural production function fully meets the needs of the unique set of problems confronted in this study,[1] most particularly the need to consider simultaneously so many distinct inputs over such a wide range of availabilities, it has been necessary to devise a new approach to the problem. Chapter XII of Part I of this study addresses itself to this problem and it is essentially the production functions therein developed that are discussed below.

These functions are developed and combined in this report for both crops and livestock. The description which follows will be that used

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[1] For discussion of other types, see Heady and Dillon, Agricultural Production Functions, Iowa State University, 1961.

for crops. By substituting "surviving livestock" for "surviving crop-land," the description applies also to livestock.

Postattack crop production is considered, to a first approximation, to be limited by the proportion of land and of farm managers that are available. The smaller of these two inputs is taken to be the limiting constraint for the entire crop production function. Land losses are considered to be uniformly distributed so that the same proportion of good and poor land is contaminated by fallout.[1] Similarly, good and poor managers are taken to survive in identical proportions.[2] Hence, there is reason to expect an output roughly proportional to the amounts of these inputs. (The "law of diminishing returns," which would be expected in a normal situation, would result in less than a proportional loss of output for a given loss of input.) The curve used in this study to show the effect of land and management input losses is a linear function from 0 to 1.

LAND AND FARM MANAGEMENT INPUT RESPONSE CURVE

Postattack farm output as a fraction of preattack output

Fraction of normal input available postattack
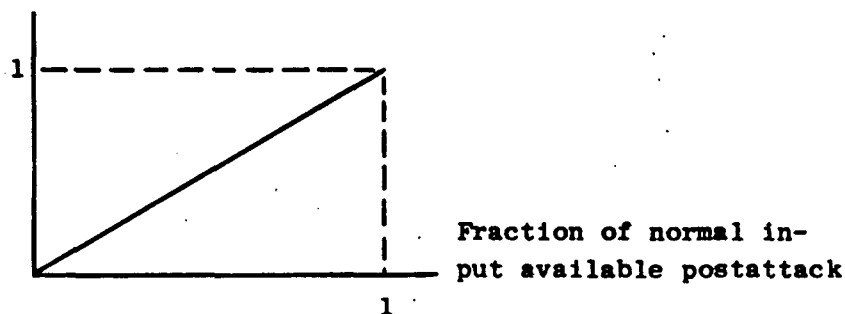
1/ Although land not normally used for farming could conceivably be farmed postattack, doing this in the first year would be most unlikely. Heady observes that even in the long run, "agriculture . . . has little opportunity to secure added land as a means of expandings its basic plant." Earl O. Heady, Economics of Agricultural Production and Resource Use, Prentice-Hall, New York, 1952, p. 694.

2/ Since good land and good farmers tend to be concentrated in the more vulnerable areas around large cities, there is some basis for the belief that production losses would be more than proportional to acreage and number of farmers lost. On the other hand, efficient reallocation of land and extension of management talents where necessary could help to alleviate losses.

As an example of the constraints imposed by inputs: if 70 percent of the cropland were free from serious contamination postattack and 80 percent of the farm managers were available for conducting farm operations, land would be taken to be the limiting constraint and the postattack crop output would be 70 percent of the preattack output (all other factors remaining constant). However, further adjustments are necessary, since crop response is also a function of the amounts of fertilizers, pesticides, fuel, and other inputs, and it is by no means likely that these will all survive in precisely the same proportion. Availability of each input must be related to the decreased availability of farmland and farm managers. For example, if land is the limiting constraint with a postattack availability of 70 percent, and if 60 percent of pesticides are available postattack, the pesticide requirement relative to the amount of the limiting constraint is not .60 but .60/.70, or .86.

The response of each non-proportional input is then found from its production function value at this relative input fraction. The input production functions which have been used are based on the analysis and expert opinion summarized in the Part I report. These functions are shown in this report in Figure 2 for the response of crops and Figure 3 for the response of livestock.

Linear functions are assumed for all inputs (except fuel and farm labor, which have been handled together and for which a special non-linear response has been postulated) in order to provide a conservative function. Normally a curve of diminishing returns (convex upward) could be expected between the estimated points.

A second assumption is necessary concerning the response curves devised because, with the exception of fertilizer and farm labor, no information was obtained for greater than normal amounts of an input. Therefore, the response to input fractions greater than 1 was simply assigned a value of 1 (i.e., no additional gain is obtained from having greater than normal amounts). Such a procedure is clearly a conservative one and one probably not much in error for most of the cases where this problem arises. (For example, having greater than normal amounts of electric power available is unlikely to add significantly to output.)

Third, over-all production is assumed to be the simple product of the response factors for all inputs, as in the Cobb-Douglas function. This assumption is also conservative for most cases of input loss, because the responses are likely to be less than completely cumulative (e.g., lowered fertilizer applications may reduce requirements for fuel, labor, and pesticides because crop growth will be less).

FIG. 2
CROP PRODUCTION FROM INDICATED AMOUNTS OF INDIVIDUAL INPUTS IN FIRST
POSTATTACK YEAR   (ALL OTHER INPUTS AT NORMAL LEVELS)

FUEL

WITH DOUBLED
MANPOWER

WITH NORMAL
MANPOWER

1 NEW EQUIPMENT
2 COMMERCIAL SEED
3 ELECTRIC POWER
4 PESTICIDES

0   100   0   100

PERCENT OF NORMAL FUEL   PERCENT OF NORMAL INPUT

FRACTION OF NORMAL
CROP PRODUCTION

$\lfloor_0 \rfloor$

FERTILIZER

1   PHOSPHATE
2   NITROGEN, POTASH
3   ALL FERTILIZERS

0   100   200

PERCENT OF NORMAL FERTILIZER

FRACTION OF NORMAL
CROP PRODUCTION

$\lfloor_0 \rfloor$

17
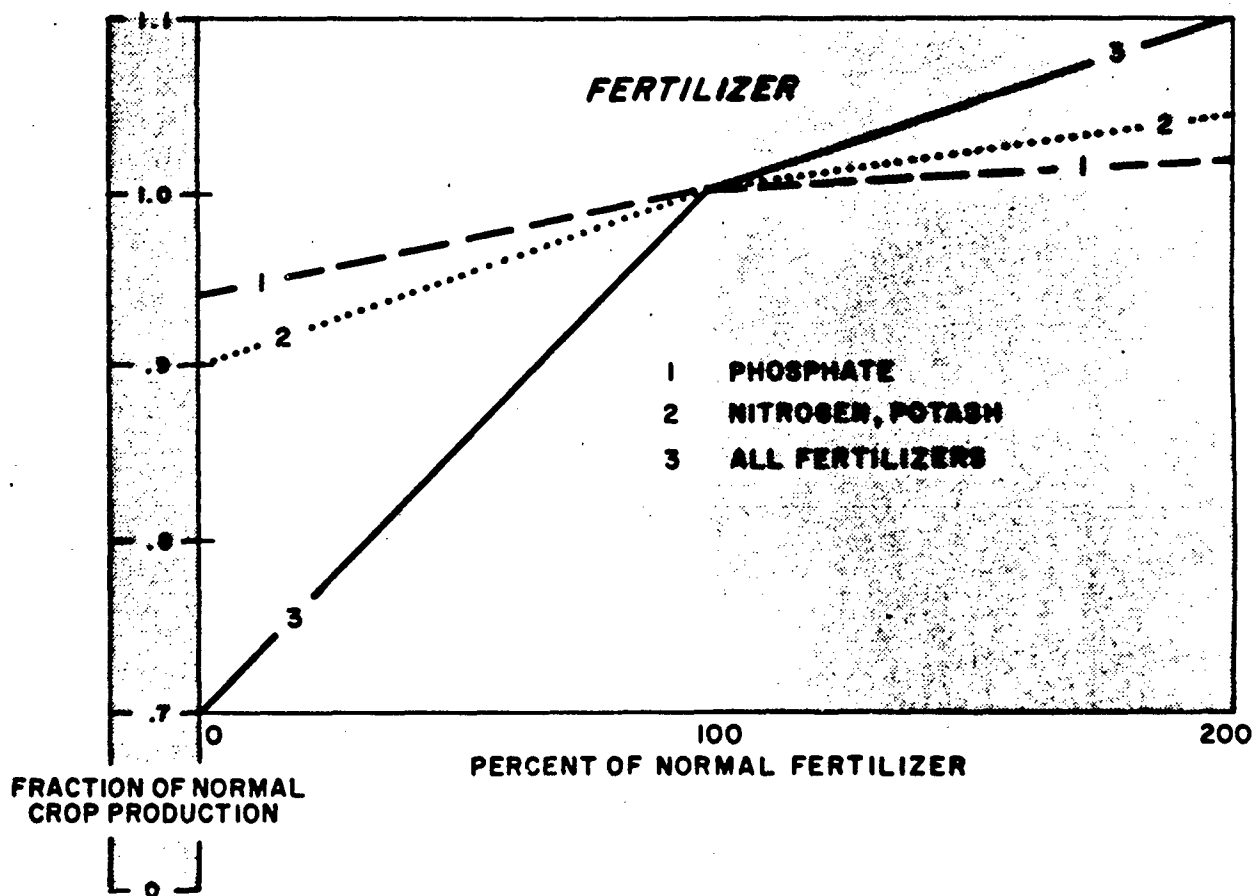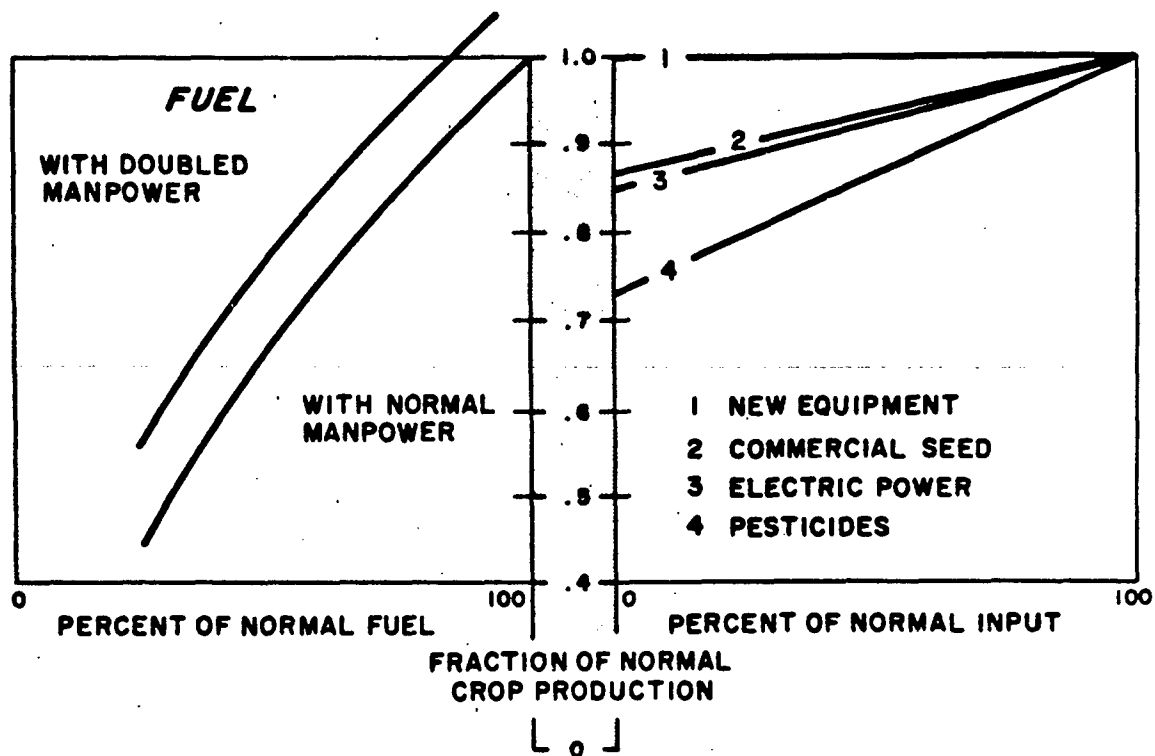
FIG.3

LIVESTOCK PRODUCTION FROM INDICATED AMOUNTS OF INDIVIDUAL INPUTS IN FIRST POSTATTACK YEAR (ALL OTHER INPUTS AT NORMAL LEVELS)

WITH DOUBLED MANPOWER

WITH NORMAL MANPOWER

FUEL

1 NEW EQUIPMENT
2 COMMERCIAL SEED
3 PESTICIDES
4 ELECTRIC POWER

PERCENT OF NORMAL FUEL

PERCENT OF NORMAL INPUT

FRACTION OF NORMAL LIVESTOCK PRODUCTION

FERTILIZER

1 POTASH
2 NITROGEN
3 PHOSPHATE
4 ALL FERTILIZERS

PERCENT OF NORMAL FERTILIZER

FRACTION OF NORMAL LIVESTOCK PRODUCTION

18
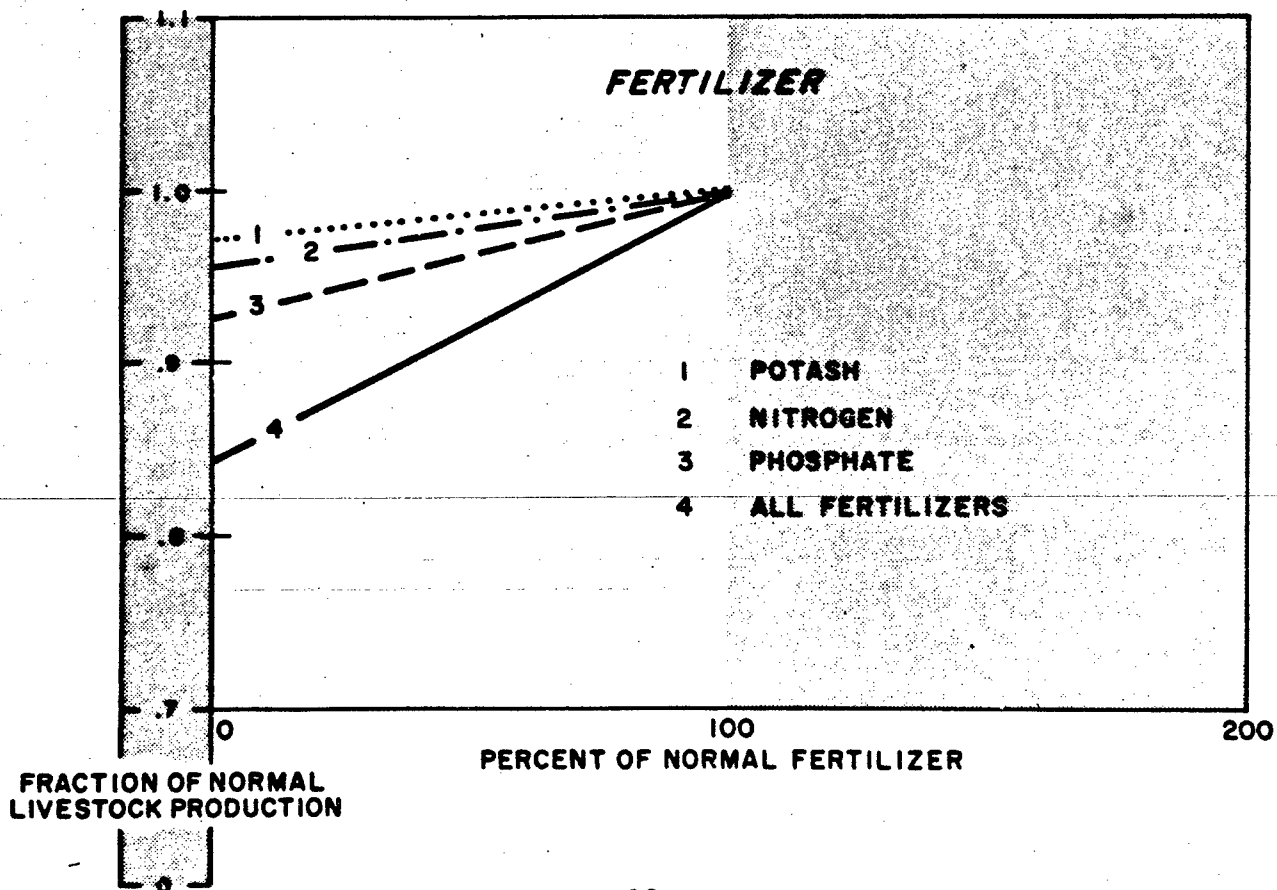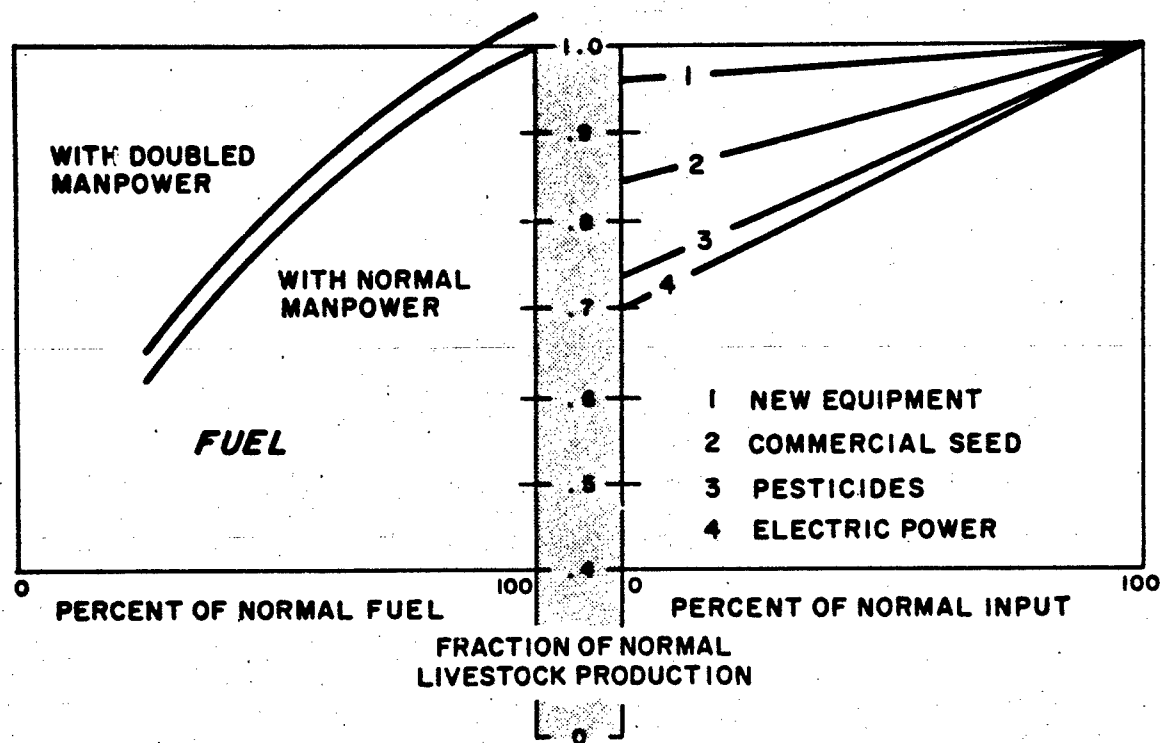
These three simplifying assumptions are necessary to handle the ex-
tremely complex individual behaviors and the interactions among the
agricultural inputs. They do introduce some error into the analysis,
but since all three assumptions are conservative, they will tend to err
toward a low estimate of output. Thus qualified, the aggregate response
function can be expressed in the relatively straightforward (but lengthy)
form of:

$$Q = \min (L, Mgt) \cdot f(N) \cdot f(P) \cdot f(K) \cdot f(Pe) \cdot f(E) \cdot$$
$$f(F+M) \cdot f(S) \cdot f(W) \cdot f(Eq) \cdot f(Mnr) \cdot f(Lim)$$

where

Q = output relative to normal

$\min (L, Mgt)$ = minimum of fraction of Land or fraction of Farm
Managers available

$f(N)$ = production function for Nitrogen Fertilizer

$f(P)$ = production function for Phosphate Fertilizer

$f(K)$ = production function for Potash Fertilizer

$f(Pe)$ = production function for Pesticides

$f(E)$ = production function for Electric Power

$f(F+M)$ = production function for Fuel and Farm Manpower

$f(S)$ = production function for Seed

$f(W)$ = production function for Water

$f(Eq)$ = production function for Farm Equipment

$f(Mnr)$ = production function for Manure

$f(Lim)$ = production function for Liming Materials

Agriculture is more self-sufficient than most industries in that
many of its principal inputs are located at the site. Land, labor, and
livestock are an integral part of the farm. Moreover, from a short-run
point of view (i.e., before large numbers of replacements become neces-
sary), agricultural equipment is mainly local to the farm. It would be
inappropriate, however, to limit a vulnerability analysis to these farm
inputs, for it is clear that modern farm operations are heavily depend-
ent on a continued flow of resources from a number of industrial sectors
of the economy. Fuel, soil nutrients, pesticides, electric power, com-
mercial seed supplies, and irrigation water are chief among the inputs

located off the farm that have a major influence on agricultural production. Determining the vulnerability of agriculture to nuclear attack, therefore, requires that some estimate be made of the postattack condition of both these farm and non-farm inputs.

In the absence of a complete description of national priorities among the demands for each type of input, it is assumed that agriculture could rate a relatively high priority. Where inputs are available at all, they could be partially diverted to, or at least not completely denied to, agricultural uses.

Throughout the analysis of all inputs, fallout has been given special consideration. Not only would fallout contaminate vast amounts of land but the loss of a skilled labor force due to fallout effects can as effectively shut down an agricultural enterprise in early postattack periods as can physical destruction. Fallout would affect operations on the farm, operations at facilities that provide the final input product or service, and operations at prior input processing operations. Hence, to evaluate the effects of a nuclear attack on agriculture one must take account of the fallout, as well as the blast effects (1) at the farm, (2) at the final input stage, and (3) at prior processing and input facilities.

Since fallout effects vary with shelter conditions, it has been necessary to assume a protection condition for the population. The standard condition chosen is that of "available shelter or protection," which assumes protection equivalent to that of an ordinary home basement. This type of shelter can reduce the radiation exposure to one-twentieth of the "open field" intensity. (No special protection, i.e., normal activity, reduces exposure to about one-half of the open field intensity.) Although a home basement does not represent the optimum in fallout protection (1/200 to 1/1,000 or even better could be obtained if the population were provided with special shelters), it represents a better than average shelter condition presently obtainable in view of the existing state of preparedness. If an extensive fallout protection program were to be adopted in the United States, better average protection might be assumed.

A reasonable permissible limit for emergency radiation exposure in the postattack environment is frequently assumed to be about 100 roentgens for the general population[1] to 200 roentgens for essential

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[1] Systems Analysis of Radiological Defense, Stanford Research Institute, November 1958, p. 79.

workers.[1,2/]   Since both workers and their families are of concern in re-
habilitating an area, an average of these two values (150 roentgens) is
used in this report as a limit of "effective biological dose" (EBD) for
all industrial and farm workers. An effective dose of 150 roentgens will
cause slight injury and some temporary incapacitation but it is not
likely to result in prolonged illness or death.

A one-twentieth exposure factor shelter will limit the occupants'
radiation to 150 roentgens in an area with as high as 3,000 roentgens
"open field" EBD. Since most of the fallout data were available in
terms of radiation intensity at H plus 1 hr rather than as EBD, it was
necessary to convert from H plus 1 hr values to EBD to obtain a measure
of worker availability. This was done by assuming the H plus 1 hr values
to be numerically equal to the EBD limit (3,000 roentgens/hr @ H + 1 hr =
3,000 roentgens EBD). This is approximately true for points about 200
miles downwind of a burst. For closer locations, fallout arrives earlier
and the biological dose is greater than the H plus 1 hr dose rate; it is
twice as great for points about 50 miles downwind and three times as
great for points within 20 miles of the burst. The indicated estimates
of manpower availability, particularly for industry, therefore would in
some cases require better than one-twentieth exposure protection. The
effects of variations in exposure standards are considered in Chapter IV.

Since the smallest area unit for which radiation coverage was avail-
able is the county,[3/] the fallout coverage of farms has been determined
from county-wide data, and their vulnerability is discussed in Chapters
III and IV. However, for some types of industrial operations, special
computer runs were already available which determined physical destruc-
tion and radiation coverage by plant. This information has been utilized
wherever it was available.[4/] The following were considered as losses to
industrial production and services during the first postattack year:

1/ A System Analysis of the Effects of Nuclear Attack on Railroad Trans-
    portation in the Continental United States, Stanford Research Insti-
    tute, April 1960, p. 60.
2/ Civil Defense Hearings, March 28-31, 1960, House of Representatives
    Government Operations Committee, Government Printing Office, Washing-
    ton, D.C., pp. 6 and 125.
3/ Obtained from working papers used in the preparation of the Attack
    Damage Digest.
4/ Electric power generating stations, transformer facilities, crude
    oil refineries, and railroad facilities were among the categories
    for which special runs were available.

1. Physical losses. Wherever physical plant destruction estimates were separately available, these were used.

2. Fallout losses. Where the figures were available (often they were not), all plants (either by plant or by county) receiving over 3,000 r/hr at H plus 1 hr were considered lost, whereas those receiving less than 3,000 r/hr at H plus 1 hr were considered operational.

3. Fallout losses and physical losses not included above.

   a. Over 10,000 r/hr at H plus 1 hr. All plants located in counties receiving this amount of radiation were considered lost.

   b. 1,000 to 10,000 r/hr at H plus 1 hr.

      (1) Early 1960's attacks. One-third of the plants located in counties receiving this amount were considered lost.

      (2) Late 1960's attacks. Two-thirds of the plants located in counties receiving this amount were considered lost.[1]

A vulnerability approach tied closely to fallout effects might be criticized for failing to provide for the possibility of substituting available workers from less important sectors of the economy for those lost in the more important sectors, and for decontaminating the physically undamaged plants and putting these plants back into operation. However, such an argument ignores two operational problems which are likely to severely inhibit early recovery (particularly in the absence of widespread civil defense preparations): (1) plants, and particularly machinery, cannot long remain idle without deteriorating unless special efforts have been made to preserve them in an operable condition; and (2) more than mere numbers of workers are needed to operate a plant-- skills and familiarity with an operation are also required.

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[1] Within the range 1,000 to 10,000 r/hr, the mean county radiation intensity for the early 1960's attacks tends to be low, while for the later 1960's attacks, the mean is higher. Hence, higher fractional loss for the later series of attacks was assumed.

These problems are particularly important *from* a short-run (first postattack year) standpoint, since equipment may eventually be repaired and people can be retrained. However, as attacks increase in severity and more people are lost, the capability for reallocating workers decreases. Figure 4 shows the estimates of postattack availability of workers under the "available shelter" condition.[1] Clearly, there would be many problems of substitution following either of the attacks directed at population centers.

Outline of Succeeding Chapters

The vulnerability of each of the major input resources to agriculture is analyzed in Chapters III through XI. Although the analyses of individual inputs vary, each chapter generally includes a discussion of the background environment of the input, description of its normal availability or processing methods, appraisal of the input system's most vulnerable aspects, and quantitative estimates of its first postattack year net availability under four hypothetical attack situations.

In Chapter XII, results of the individual input vulnerability assessments are converted to assessments of postattack farm production by means of the agricultural production functions described above. The methodology and data for summarizing all parts of the analysis are developed in considerable detail there.

The last chapter contains a discussion of possible individual and administrative adaptations, economic problems, and environmental factors which could be important in determining postattack farm production.

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[1] "Availability of workers" should not be confused with "survival of workers" since the seriously injured are not counted under availability.

FIG. 4

U.S. WORKING FORCE AVAILABLE FOR WORK IN FIRST
POSTATTACK YEAR (ASSUMING USE OF BASEMENTS AND
OTHER EXISTING FALLOUT SHELTERS)

PERCENT OF PREATTACK

| 0 | 20 | 40 | 60 | 80 | 100 |

EARLY 1960s
MILITARY ATTACK
95

EARLY 1960s MIL.-
POP. ATTACK
31

LATE 1960s
MILITARY ATTACK
78

LATE 1960s MIL.-
POP. ATTACK
20
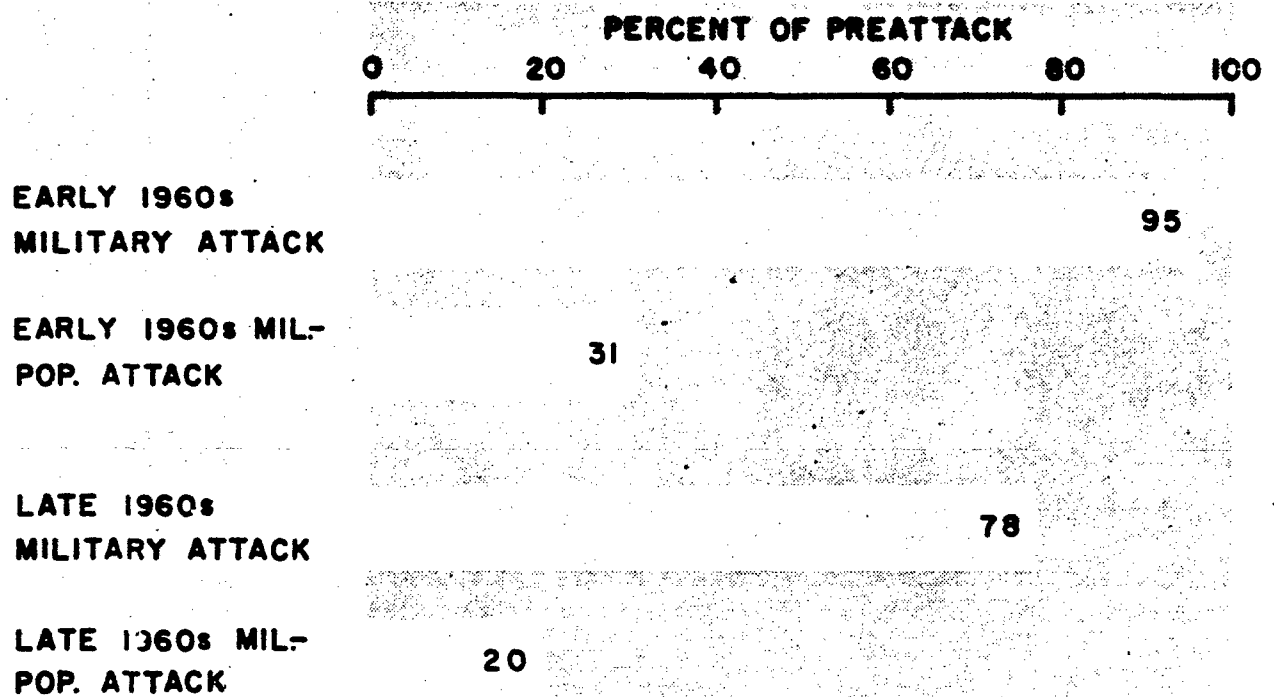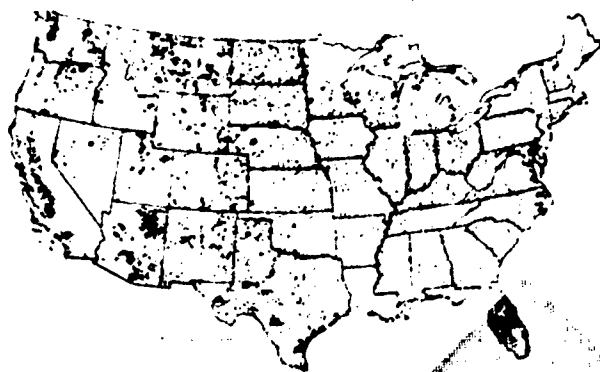
SOURCE

TOTAL LAND IN FARMS

LAND

DISTRIBUTION

HOMES

FACILITIES

CROPS

PASTURE
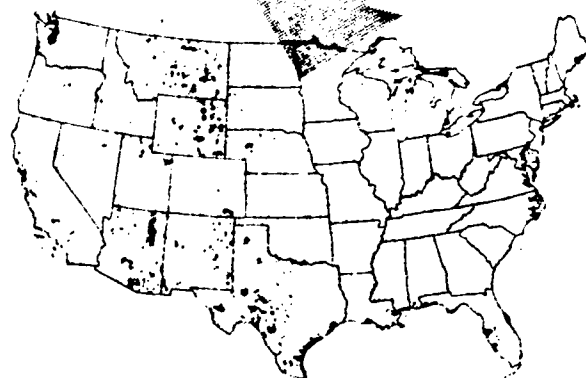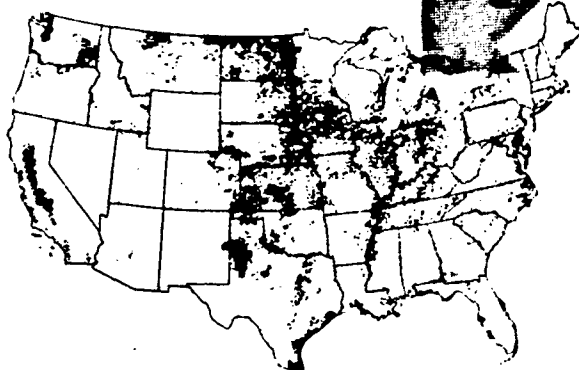
Chapter III

LAND

Background

A nuclear attack could affect land productivity by killing crops and livestock, by destroying farm facilities, by rendering the area unhabitable because of fallout, or by preventing future farm production because of contamination, disease, or isolation. Each of these effects could be the limiting constraint to production in a postattack environment.

Immediate losses to crops, livestock, and farm facilities would be caused by the direct blast and fallout effects from nuclear bursts, as well as by the indirect effects of conflagrations, floods, and pestilence that might accompany an attack. The overwhelming hazard is from fallout, since farms are so dispersed that relatively few would be in areas immediately surrounding a nuclear burst. The small hazard of blast effects over most of the country may be seen from the estimate that less than 3 percent of the population of non-metropolitan areas would be killed by blast even under the heaviest of the four hypothetical attacks analyzed in this report.[1] Farm production losses due to blast effects have therefore been ignored.

Losses from fire damage would in many cases be greater than blast losses, because the area of fire spread is frequently larger than the blast area. Also, fire damage would be greater following an air burst than following a surface burst. One study indicates that the expected total fire spread from a 10-megaton air burst would be at least 800 square miles, and could be 1,300 square miles or more.[2] In contrast,

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[1] Attack Damage Digest, Stanford Research Institute, December 1959, revised April 1961. SECRET, RESTRICTED DATA.

[2] Jewell, W.S., and A. B. Willoughby, A Study to Analyze and Improve Procedures for Fire Damage Assessment Following Nuclear Attack, Broadview Research Corp., Burlingame, California, October 1960, Table 3. The maximum expectation in Indiana is 1,080 sq mi in October; in Oklahoma, 1,260 sq mi in April and July; and in central California, 1,300 sq mi in October. The maximum in some forest areas is as high as 10,000 sq mi.

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the maximum area of significant blast damage (1.6 pounds per square inch overpressure) for a 10-megaton air burst is about 850 square miles. Comparable fire spread estimates are not available for surface bursts.

Another point to consider is that the fire spread from multiple bursts on one target is essentially limited to the area of spread from one bomb, whereas the fallout hazard increases in direct proportion to the number of ground bursts. Finally, a great deal of the area of fire spread would be coincident with fallout hazard areas. It can be seen that the extreme uncertainty in fire spread estimates would make a generalized damage estimate difficult. Therefore, in this analysis, losses from fire spread under nuclear attack have been ignored.

Although ignoring the possible damage from fire spread may involve greater error than ignoring blast losses, fire spread damage would probably be minor compared with fallout damage in a heavy attack. A discussion of land contamination and livestock radiation exposure follows.

Land Contamination

Contamination of growing crops is due to both deposition of fallout material on plants and the uptake of radioactive minerals by plants from the soil or water.[1] Deposition is the primary hazard for crops growing at the time of attack, and is a hazard even years after an attack because of delayed fallout. However, root crops and most other crops can be cleaned or peeled to remove deposited fallout material. Uptake of radioactive material into the plant is more difficult to counteract, although several cropland reclaiming methods such as decontamination and the addition of calcium or other diluting minerals can be employed. Since complete theories of the mechanisms of deposition, uptake, and decontamination have not been developed, fallout tolerance and protective actions for crop production cannot yet be recommended with confidence.

One list circulated within the Department of Agriculture indicated that for a generally contaminated region, the limit of fallout intensity under which crops could safely be produced is about 100 r/hr (measured at H plus 1 hr) for leafy vegetables, 1,000 r/hr for other food crops,

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[1] For relative contributions, see Ichiwaka, Abe, and Eto, "Evaluation of the Origins of Strontium 90 Contained in Wheat Plant," Science, Vol. 133, June 23, 1961.

and higher levels for cotton, sugar, and oil crops.[1] Those assumptions are quite similar to the one adopted in this and other SRI reports that a 1,000 r/hr limit (at H plus 1 hr) could be tolerated in an extremity for production of crops during the first postattack year. Extensive decontamination actions and a one- or two-year fallow period could probably be used to reclaim land subjected to as high as 10,000 r/hr.

A more recent Department of Agriculture standard based on the Strontium 90 hazard indicates average fallout limits for food-producing areas of as low as 100 r/hr,[2] but these limits may be based on fairly high standards. Other recent research findings tend to downgrade the hazard of Strontium 90, particularly after the first year.[3] The 100 r/hr limit therefore appears to be unnecessarily restrictive.

Contamination of land by fallout can also be considered on the basis of the "denial" period before re-entry and resumption of normal activities is possible. The denial period will depend on the permissible radiation exposure and other environmental factors, as well as on the levels of fallout. For example, an analysis that assumed relatively low radiation tolerances indicated that the general population could permanently re-enter areas of 1,000 r/hr fallout at H plus 1 hr within six months.[4] One analysis of agricultural denial times found that reoccupation of 1,000 r/hr fallout areas would be possible within three months,[5] and another recommended limiting work periods in such areas to one hour per day if work is resumed within a few days and to three hours per day if reoccupation is delayed for a month.[6] A study of railroad workers

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1/ Land Contamination Levels above Which Critical Agricultural Production Materials Are Denied for Production of Crops and Livestock, Unpublished Memorandum, U.S. Dept. of Agriculture, Washington, D.C., 1959.

2/ Radioactive Fallout in Time of Emergency, ARS 22-55, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, D.C., April 1960, Table 6.

3/ Work by K. H. Larsen and U.S. Dept. of Agriculture studies, much of which is not yet published.

4/ Systems Analysis of Radiological Defense, Stanford Research Institute, November 1958, Table X.

5/ National Damage Assessment Report on Food and Agricultural Resources, Operation Alert 1958, U.S. Dept. of Agriculture, Damage Assessment Defense Planning Committee, Washington, D.C., June 1958, p. 7.

6/ U.S. Dept. of Agriculture, Radioactive Fallout in Time of Emergency, op. cit., Table 3.

concluded that essential field crew tasks could be resumed in 1,000 r/hr areas within ten days of a detonation if high radiation limits are accepted.[1] All of these denial time values are consistent with the 1,000 r/hr fallout limit specified in the present study if differences in the assumed radiation tolerance are taken into account.

Livestock Exposure to Radiation

Although many animals are somewhat more resistant to radiation injury than humans,[2] livestock are generally less able than people to survive fallout because fewer precautions against radiation exposure or ingestion of contaminated food and water can be taken.

People taking shelter in home basements, for example, can withstand an open field "effective biological dose" of up to 3,000 roentgens without serious harm, whereas the majority of farm animals would be killed by such an intensity.[3] For animals in a normal wooden shed, an open field dose level exceeding roughly 1,000 roentgens would be fatal. As indicated in Chapter II, a 1,000 roentgen dose results from a 1,000 r/hr fallout intensity at locations 200 miles downwind of a burst and from lesser intensities at closer locations. Thus, the maximum fallout level for survival of most livestock in shed-type shelters would appear to be about 1,000 r/hr at H plus 1 hr.

For poorer shelter on the open range or for regions close to a burst, the limit would be considerably lower. In addition, animals grazing on contaminated pasture would be subjected to internal radiation from ingested materials. One calculation indicated that lethal damage to the

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[1] A System Analysis of the Effects of Nuclear Attack on Railroad Transportation in the Continental United States, Stanford Research Institute, April 1960, Table 15.

[2] Effects of acute whole-body radiation are considered to be 50 percent lethal for humans at about 450 roentgens (Effects of Nuclear Weapons, op. cit., Fig. 11.57), but comparable lethality for cattle, sheep, and hogs is about 550 r, and for poultry is about 900 r (communication from Mr. K. J. Nicholson, U.S. Dept. of Agriculture, based on data supplied by Maj. R. E. Benson, AEC, February 13, 1961).

[2] U.S. Dept. of Agriculture, Radioactive Fallout in Time of Emergency, op. cit., Table 4.

thyroid gland could result from grazing under even very low fallout levels,[1] but more recent findings indicate that the use of iodized salt can greatly restrict retention of radioactive iodine. Also, other actions can be taken to shelter range livestock and supply them with prepared feeds during early periods, so that most normally unsheltered livestock could probably be saved in fallout levels of 100 r/hr.

Contamination of milk from grazing cattle is also a potential problem at even low fallout levels. It has been judged unsafe for adults to use milk from dairy cattle exposed to 10 r/hr until several days have elapsed, and unsafe for children until several months have elapsed.[2] The hazard can be greatly reduced by such measures as (1) delaying resumption of milk use even longer (cows in areas of 100 r/hr can produce milk after 35 days that is safe for adults), (2) by using stored milk in canned or dried form, particularly for children, (3) by feeding cows hay and other prepared feeds that are normally in good supply in dairy areas, and (4) by decontaminating milk by recently developed ion-exchange methods. In view of these possibilities, dairy cattle vulnerability is not considered separately from that of other livestock.

Vulnerability of livestock to fallout is considered only on the basis of whether shelter is available. Sheltered livestock are assumed to be one-tenth as vulnerable as unsheltered livestock; i.e., sheltered livestock can tolerate up to 1,000 r/hr fallout levels while the limit for unsheltered animals is only 100 r/hr. It is estimated that while most hogs and milk cows can be given shelter, only about 15 percent of the beef cattle can be so protected.[3] On the basis of 1958 values for dairy, beef, and swine production[4] and on the assumption that shelter for these animals is representative of all livestock (beef, dairy, and

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1/ The Postattack Food Situation, Stanford Research Institute, October 1957, p. 14. SECRET.

2/ U.S. Dept. of Agriculture, Radioactive Fallout in Time of Emergency, op. cit., Table 5.

3/ A conservative estimate, since some beef is obtained from dairy stock, which are more often sheltered. Part I, Chapter VII, indicated that covered shelter is normally used for beef cattle only in some areas of the northeastern quarter of the country, which accounts for about 30 percent of national beef production. About half of the beef cattle in this section are sheltered.

4/ Agricultural Statistics 1959, U.S. Dept. of Agriculture, Government Printing Office, Washington, D.C., 1960, p. 443.

swine accounted for 90 percent of the 1958 farm value of dairy and meat animals and poultry), the proportion of sheltered livestock is estimated as 43 percent.[1]

Vulnerability Summary

Inasmuch as the true fallout vulnerabilities of both crops and livestock are uncertain, calculations were made to compare the probable coverage to be expected with various fallout intensities. The estimates of fallout coverages were made with the Damage Assessment System fallout model.[2] The results for several commodities are indicated in Table 1.

Table 1 shows that most agricultural resources are affected similarly by a given nuclear attack. For this reason, it appears justifiable to use a single estimate for fallout coverage of all crops under a given attack, and another for fallout coverage of all livestock. The most suitable measures in Table 1 to use for such estimates are "All Cropland" and "All Cattle."

Cropland survival would be the residual fraction after subtracting the losses as indicated in Table 1. (For example, if the tolerance limit is 1,000 r/hr and 59 percent of the cropland is subjected to more than 1,000 r/hr under the assumed late 1960's military attack, the "safe" cropland would amount to 41 percent. If the tolerance limit is 3,000 r/hr, the "safe" amount is 76 percent.) The survival of livestock is shown in Table 2 for two tolerance limits. [For the late 1960's military attack, 46 percent of the sheltered livestock would be in less than 1,000 h/hr fallout and 25 percent of the unsheltered livestock would be in less than 100 r/hr fallout. Since 43 percent are sheltered and 57 percent are unsheltered, total survival would equal (.46 x .43) + (.25 x .57), or 34 percent.]

1/ Value of sheltered beef cattle is 1.5 percent of $10.1 billion (in 1959), or $1.5 billion. Value of sheltered dairy cattle and swine is 90 percent of $6.5 billion, or $5.8 billion. Total value of sheltered animals is $7.3 billion, or 43 percent of $16.6 billion.

2/ For description, see Vulnerability Functions, Stanford Research Institute, December 1957.

Table 1

FALLOUT COVERAGE OF AGRICULTURAL RESOURCES

Fallout (r/hr at H + 1 hr)	Alfalfa 1/	Wheat 2/	Corn 2/	Potatoes 1/	All Crop-land 3/	Hogs 4/	Milk 5/	All Cattle 4/ (incl. dairy)
Early 1960's Military Attack								
>100 r/hr	%6/	%6/	%6/	%6/	20%	25%	20%	20%
>300 r/hr	10	9	9	11	9	9	9	9
>1,000 r/hr	4	4	3	5	4	3	4	4
>3,000 r/hr	2	2	2	2	2	2	2	2
Early 1960's Mil.-Pop. Attack								
>100 r/hr	6/	6/	6/	6/	44	55	68	46
>300 r/hr	29	31	32	32	27	32	45	28
>1,000 r/hr	16	17	15	19	14	14	28	15
>3,000 r/hr	7	8	7	8	7	7	15	7
Late 1960's Military Attack								
>100 r/hr	6/	6/	6/	6/	81	85	73	75
>300 r/hr	82	77	81	54	74	79	61	69
>1,000 r/hr	64	66	60	44	59	56	38	54
>3,000 r/hr	29	29	23	23	24	12	14	24
Late 1960's Mil.-Pop. Attack								
>100 r/hr	6/	6/	6/	6/	91	95	94	88
>300 r/hr	91	85	93	70	87	92	90	84
>1,000 r/hr	79	75	77	60	73	75	70	70
>3,000 r/hr	54	53	48	52	48	29	40	39

1/ In terms of weight produced in 1957.
2/ In terms of bushels produced in 1957.
3/ In terms of harvested acres in 1954.
4/ In terms of number in 1954.
5/ In terms of weight of whole milk produced in 1954.
6/ Not calculated.

Source: Derived from Attack Damage Digest.

Table 2

LIVESTOCK SURVIVAL UNDER FALLOUT

With Tolerance Limit of:	Percent of Livestock Surviving			
	Early 1960's Attacks		Late 1960's Attacks	
	Military	Military-Population	Military	Military-Population
1,000 r/hr for sheltered 100 r/hr for unsheltered	86%	67%	34%	19%
3,000 r/hr for sheltered 300 r/hr for unsheltered	94	81	51	35

From Tables 1 and 2 it may be seen that a 3:1 uncertainty in the true tolerance of crop and livestock resources to fallout can sometimes result in a 2:1 uncertainty in the amount of surviving resources. The question of tolerances for products from contaminated land therefore requires closer resolution for detailed civil defense and mobilization planning. As a first approximation for this analysis, however, 1,000 r/hr tolerances for crops and sheltered livestock (100 r/hr for unsheltered livestock) will be assumed. Crop and livestock available for agricultural production in the first postattack year under this assumption are shown in Figures 5 and 6.

These figures indicate that livestock tend to be more vulnerable to attack than crops. Other analyses based on other attack patterns have arrived at similar conclusions.[1]

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[1] Civil Defense Hearings, March 28-31, 1960, House of Representatives Government Operations Committee, Government Printing Office, Washington, D.C., pp. 80-84.

FIG. 5
CROPLAND AVAILABLE IN FIRST POSTATTACK YEAR

PERCENT OF PREATTACK

| 0 | 20 | 40 | 60 | 80 | 100 |

EARLY 1960s
MILITARY ATTACK   96

EARLY 1960s MIL.-
POP. ATTACK   86

LATE 1960s
MILITARY ATTACK   41

LATE 1960s MIL.-
POP. ATTACK   27
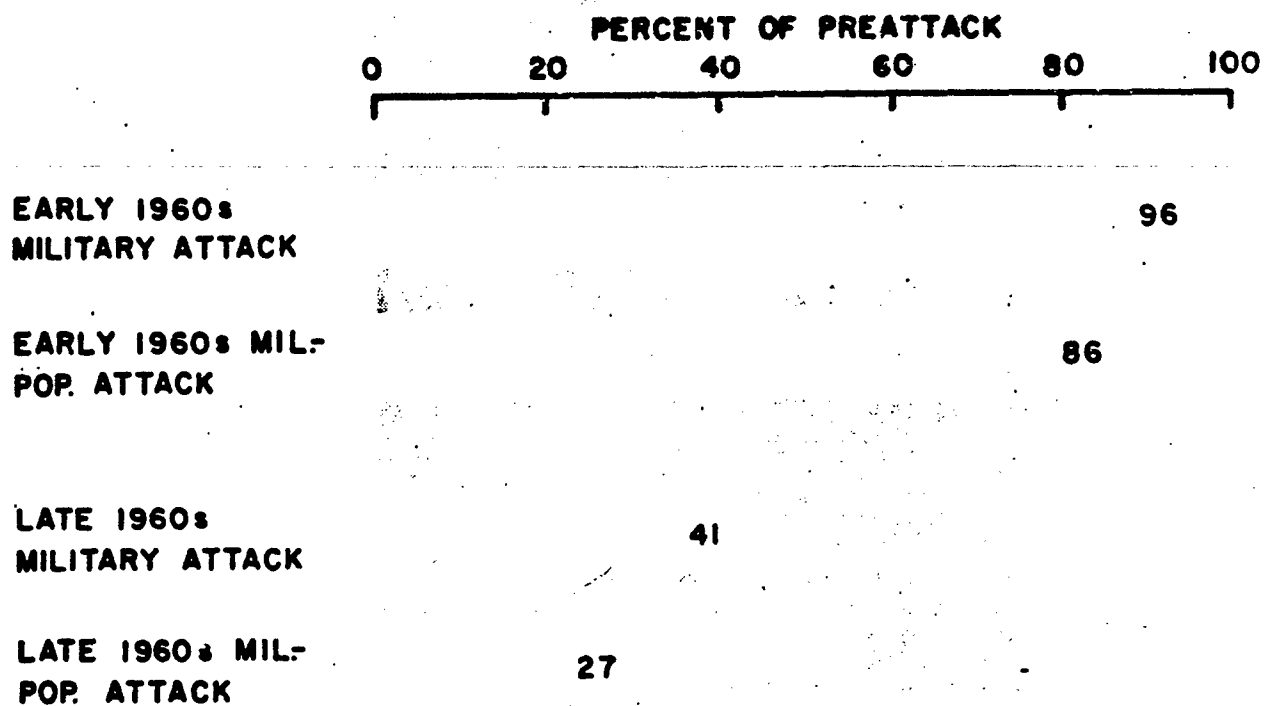
FIG. 6
PRODUCING LIVESTOCK AVAILABLE IN FIRST POSTATTACK YEAR

PERCENT OF PREATTACK

0	20	40	60	80	100

EARLY 1960s
MILITARY ATTACK   86

EARLY 1960s MIL.-
POP. ATTACK   67

LATE 1960s
MILITARY ATTACK   34

LATE 1960s MIL.-
POP. ATTACK   19

SOURCES

FARM POPULATION

FARM WORKERS

MANPOWER

DISTRIBUTION

FARMERS

NORMAL FARM LABOR FORCE

NONFARM LABOR FORCE

RESERVE
WORK
FORCE
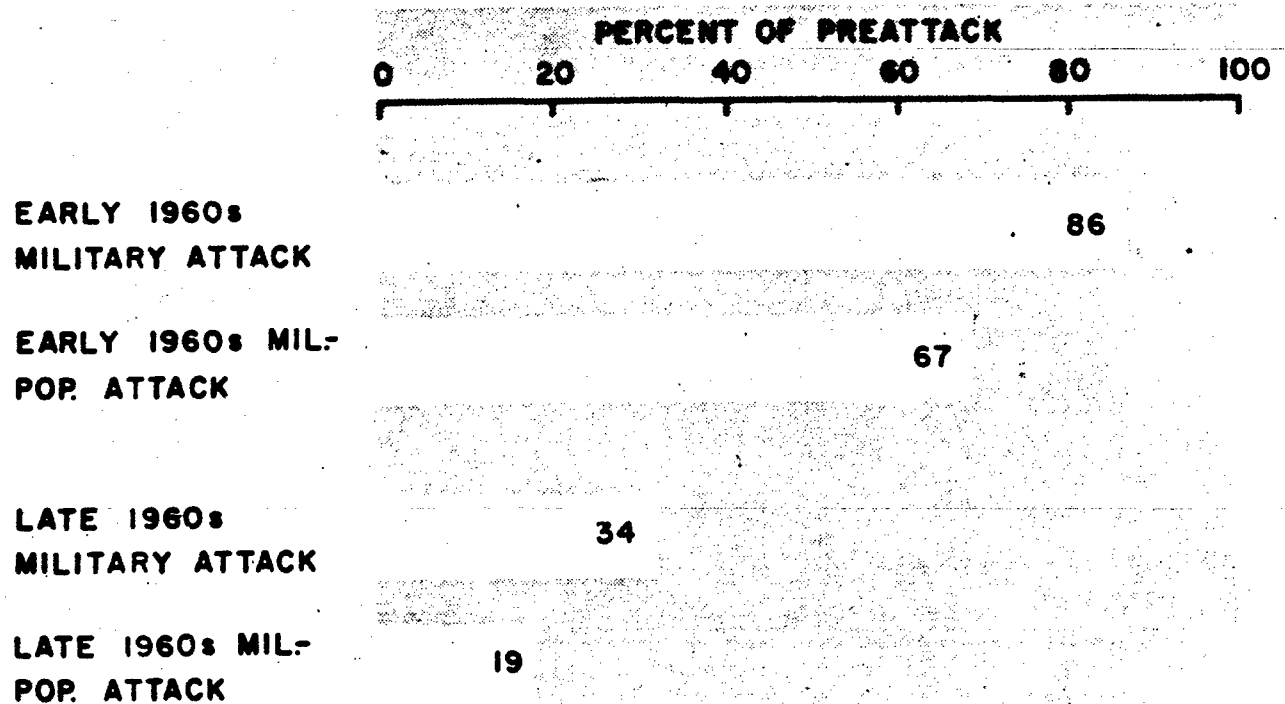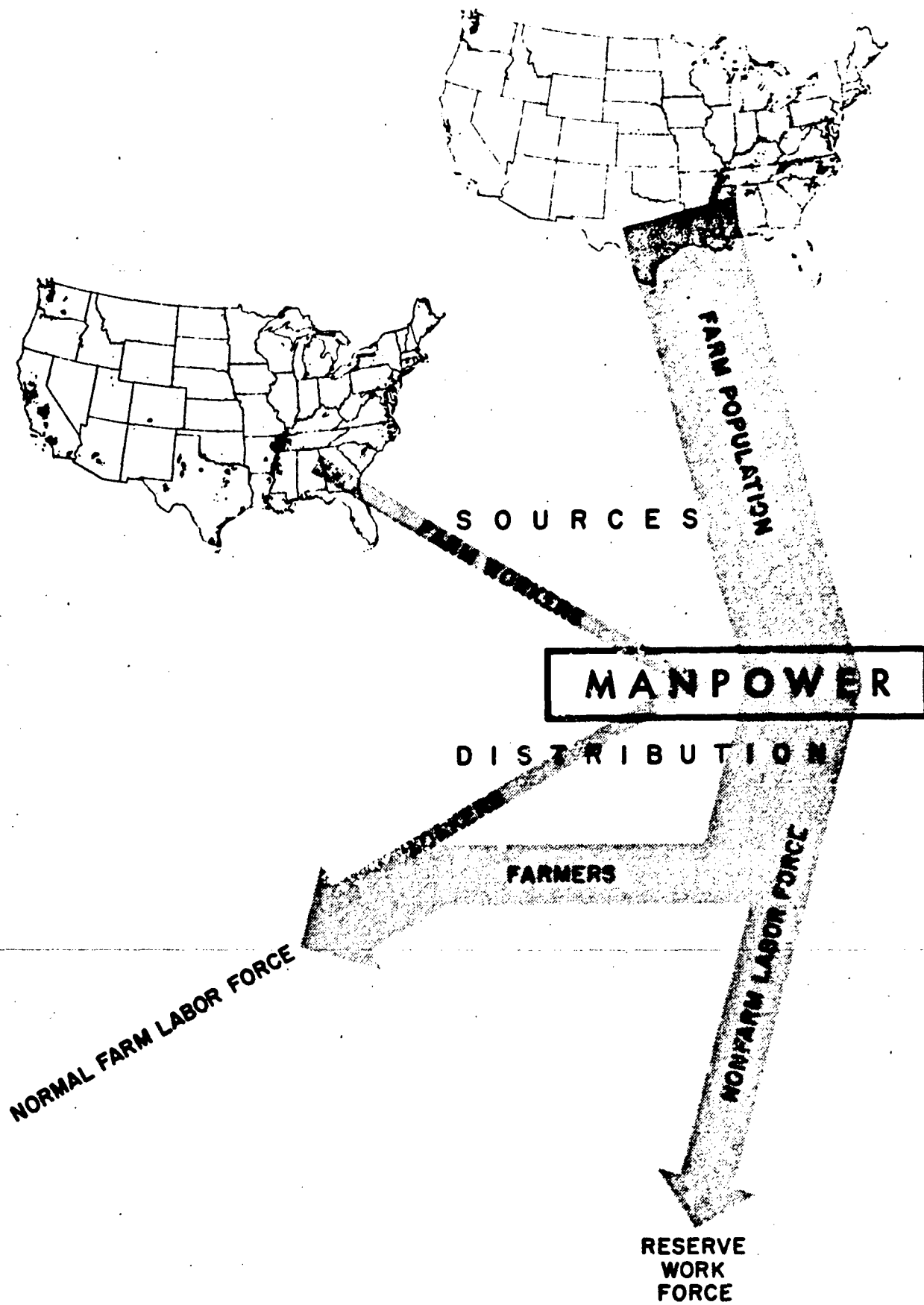
Chapter IV

MANPOWER

Background

While farmers and farm laborers provide the manpower for peacetime agricultural production, the potential labor force available to post-attack agriculture would include large numbers of people who are located in farming areas but who are normally employed in other occupations. Should the need arise, these people could be recruited for agricultural work. Moreover, most members of the rural population not actively engaged in farming can be expected to have at least some familiarity with farming methods and many of them will have had actual experience.[1] In addition, several million ex-farm residents now living in urban areas and working in non-farm occupations could probably return to productive farming, although problems of relocation and employment priorities might prevent most of them from doing so in an actual postattack situation. Manpower planners might even find it necessary to divert manpower into industry, construction, etc., and away from farming.

In any event, the labor supply most immediately available for farm work--members of the work force who either live or work on farms--is quite abundant. Therefore, farm residents and workers are the only farm labor source considered in this analysis. Non-farm residents (except those working on farms) and people not normally in the labor force (children, housewives, older people) represent a much larger labor supply that might be employed in a condition of extreme food shortage.

Economical use of the postattack farm labor supply would require the survival of adequate numbers of farm managers. Experienced farm

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1/ The value of experience is documented by a report of World War II prisoners of war in Great Britain. Their productivity improved from 38 to 75 percent as they obtained experience with the work. H. T. Williams, "Changes in the Productivity of Labour in British Agriculture," Journal of Proceedings of the Agricultural Economics Society (Great Britain), Vol. X, No. 4, March 1954.

management will be particularly valuable where the operator is able to return to farming the land to which he is accustomed. This would be the normal case since cropland losses and farm population losses tend to be similar. Even if land were to survive better than farm managers, the surviving managers in each locality could in many cases simply manage the extra farm, provided enough labor and other resources were available. Where managers survive but their land is not usable for postattack production it would be possible to utilize the operating skills of these farm managers by moving them to areas where the land could be used. However, they would need to become familiar not only with different land, but also with different crops, equipment, and techniques, so that such transfers would be accompanied by a loss in productivity.

Availability

Available farm manpower and management are considered here to include all persons not killed or seriously injured who are normally employed in agriculture (i.e., farm managers, family farm workers, farm laborers residing on farms, and farm laborers not residing on farms), or who are farm residents normally in the non-agricultural work force.

Table 3 shows an approximate breakdown of these groups, expressed as a percentage of the normal (1957-58) total farm work force. Total immediately available personnel, according to Table 3, equals 162 percent of normal needs. If relative productivities of .85 and .70 are assigned to the reserve male and female groups, respectively,[1] the effective total amounts to 49 percent.

Additional workers might be obtained if necessary from non-farm workers residing in farm areas, from residents in farm areas who are not normally in the work force, and from imported labor. However, diverting local non-farm workers into farm work might be difficult unless a genuine farm emergency were apparent. The potential supply of labor from farm residents not normally in the labor force is limited because many of these people are elderly, many of the females are housewives with young children, and the productivity of the under-18 group would be likely to be quite low. The relocation and training of imported labor from distant areas, together with the question of priority of farm work over other types of work, would pose a problem in using this possible source to

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[1] H. T. Williams, op. cit.

Table 3

PRESENT AND POTENTIAL FARM WORKERS
1957-58

	Total Number (millions)	Percent of Total Normally Working on Farms		
		Male	Female	Total
Farm Workers				
Living on farms[1]	4.5	69%	13%	82%
Living off farms[2]	1.0	14	4	18
	5.5	83%	17%	100%
Other Workers Living on Farms				
Employed, non-agricultural[1]	3.0	35	20	55
Unemployed[1]	0.4	5	2	7
	3.4	40%	22%	62%
Total Potential Farm Workers	8.9	123%	39%	162%

1/ Farm Population, U.S. Bureau of the Census—Agricultural Market-
    ing Service, Washington, D.C., June 1959, Table 3, p. 27.
2/ The Hired Farm Working Force of 1957, Agricultural Information
    Bulletin No. 208, U.S. Dept. of Agriculture, Washington, D.C.,
    June 1959, Tables 2 and 14.

augment the farm labor supply. Nevertheless, an immediately available work force of about 50 percent greater than normal plus these somewhat less accessible groups in the event of a real emergency add up to a substantial reserve for farm production. The major problem is whether they would be available for work in a postattack environment.

In view of the attack damage data that are available,[1] either of two general methods could be used to obtain estimates of the postattack condition of these manpower groups. One method would utilize the average personnel availability percentages estimated by metropolitan and non-metropolitan areas; the other would utilize H plus 1 hr radiation levels on harvested cropland.

The former assumes that the postattack condition of farm manpower in the metropolitan and non-metropolitan areas would be identical with the postattack condition of the over-all population in those areas. This method is the more conservative, since it accounts for blast as well as fallout casualties, whereas the latter method assumes that the fallout exposure of farm manpower would be identical (after correcting for shelter protection) with that of cropland over the nation. The cropland-based method is slightly optimistic, because it does not allow for the greater dispersion of cropland than of farmers. Nevertheless, this method is probably more accurate for indicating the postattack availability of farm manpower for working the remaining land; therefore, it is used in the present analysis.

Fallout Hazards

Many of the problems of protection in and re-entry into contaminated areas are discussed in Chapters II and III. In Chapter II an effective exposure of about 150 roentgens is given as the limit for persons who are expected to remain at work. In normal day-to-day activities with an average radiation exposure of one-half ("no protection"), a fallout level of 100-300 r/hr would result in a 150 roentgen effective dose. For people who have made preparations to occupy presently available fallout shelters such as basements for about one week ("available protection"), the permissible fallout level would be about 1,000-3,000 r/hr. For people who modify shelter areas to provide maximum fallout protection, stockpile

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1/ Williams, "Changes in The Productivity of Labour in British Agriculture," op. cit.

supplies for several weeks, and make other preparations necessary for decontamination and recovery ("modified protection"), the permissible fallout level could be at least 10,000 r/hr.

In Chapter III, any fallout level below 1,000 r/hr is estimated to be acceptable for farming during the first year from the standpoint of land contamination, livestock survival, and long-term acceptabilit: for the population. Therefore, some fallout protection for farm workers appears necessary if manpower and management are to remain as available as the land in postattack agriculture, and good protection will be necessary if reserve labor supplies are to be made available either to increase farm production or to divert manpower to other tasks.

Vulnerability Summary

Table 4 gives the postattack availability of farm managers, family farm workers, and farm laborers as obtained from the Damage Assessment System.[1]

Table 4

POSTATTACK AVAILABILITY OF FARM MANAGERS, FAMILY FARM WORKERS, AND FARM LABORERS AS A PERCENTAGE OF PREATTACK NUMBERS

Protection Condition	Early 1960's Attacks		Late 1960's Attacks	
	Military	Military-Population	Military	Military-Population
"No Protection"	91%	73%	26%	13%
"Available Protection"	98	93	76	62
"Modified Protection" (Values given are less than could be anticipated)	99	98	94	89

[1] For comparison, the following computed values using the metropolitan/ non-metropolitan procedure are ("available protection" condition assumed): early 1960's military attack, 97 percent; early 1960's military-population attack, 81 percent; late 1960's military attack, 82 percent; late 1960's military-population attack, 61 percent.

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The postattack availabilities of farm residents not employed in agriculture are identical to those specified for the farm employed groups given in Table 4. Total immediate surviving availability relative to the normal farm work force is given in Figure 7.

Inasmuch as food requirements for the over-all population would be less than normal because of losses in the consuming population, and opportunities for farm work would also be less because of losses in cropland and livestock, the need for farm manpower might be less than normal. In any case, it is apparent from Figure 7 that manpower and management survive in sufficient numbers to satisfy postattack farm requirements if farming populations make proper use of available fallout shelters. Extra labor, in fact, might well be available for diversion to other essential postattack activities. But beyond this benefit, proper use of farm fallout shelters will promote the ultimate objective of all civil defense measures: saving people.

FIG. 7
FARM LABOR AVAILABLE IN FIRST POSTATTACK YEAR
(NORMAL FARM WORKERS PLUS FARM RESIDENT RESERVE)

PERCENT OF NORMAL

0   25   50   75   100   125   150

EARLY 1960s MILITARY ATTACK
136
147
148

EARLY 1960s MIL.- POP. ATTACK
109
139
147

LATE 1960s MILITARY ATTACK
39
114
141

LATE 1960s MIL.- POP. ATTACK
20
93
133

NO PROTECTION
"AVAILABLE PROTECTION"
"MODIFIED PROTECTION"

45
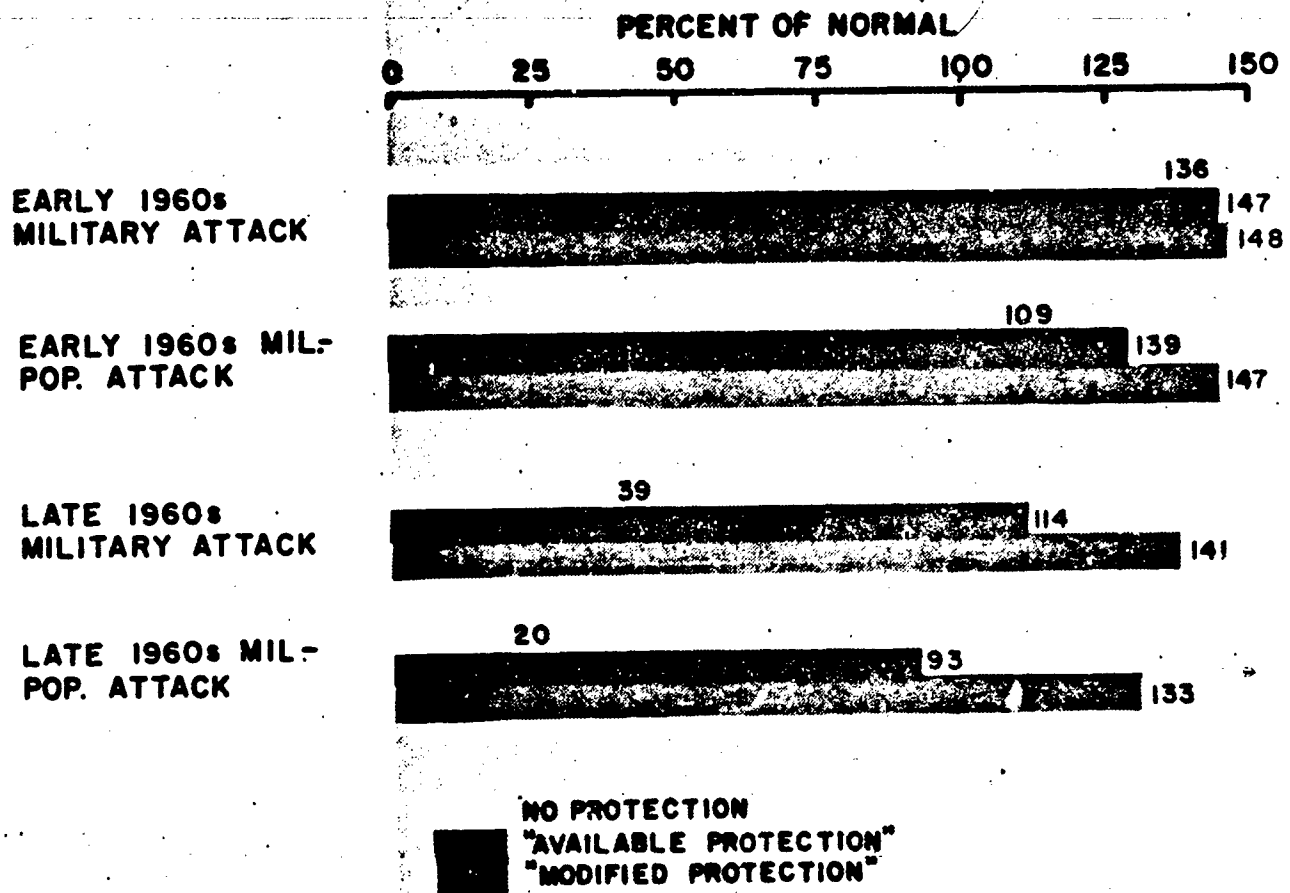
PRODUCTION

PETROLEUM FUELS

DISTRIBUTION

FARM USES

TRACTORS

AUTOS & TRUCKS

OTHER MACHINES

NON-MOTOR USES

HOUSEHOLD USES

NON-FARM USES

Chapter V

PETROLEUM FUELS

Background

Petroleum fuel is a critical input because it is the major power source for farm production. Table 5 indicates that oil and natural gas products together contribute almost 90 percent of the energy supplied to agriculture. A continued postattack supply is dependent on postattack fuel stocks and on the operations of the petroleum industry.

Table 5

ENERGY SUPPLIED TO AGRICULTURE, 1955
(Excluding Consumption for Automotive Transportation,
and Dwelling and Non-irrigation Uses of Electricity)

	Non-electric Energy (trillions of Btu)	Electric Energy Used for Irrigation and Pumping (trillions of Btu)	Total, Both Forms	
			Trillions of Btu	Percent
Coal		56.4	56.4	7.7%
Oil Products				
Gasoline	400.0			
Kerosene	40.7			
Diesel Oil	42.1			
Other Distillates	32.3			
Total Oil Products	515.1	9.0	524.1	71.9
Natural Gas Liquids				
Natural Gasoline	54.5		54.5	7.5
LPG	46.8		46.8	3.4
Total Natural Gas Liquids	101.3		101.3	13.9
Natural Gas		21.5	21.8	3.0
Hydroelectricity		25.0	25.0	3.4
Total, All Sources (trillions of Btu)	616.5	112.2	728.7[1]	
Percent	84.6%	15.4%		100.0%

[1] Schurr estimates 43 percent increase by 1975. According to his estimate, agriculture will drop from 1.8 percent of total energy in 1955 to 1.4 percent in 1975.

Source: Derived from Energy in the American Economy, 1850-1975, Schurr, et al., Resources for the Future, Inc., Johns Hopkins Press, Baltimore, 1960.

Since a relatively small number of farms account for a large proportion of the total value of agricultural production, it is of interest to examine the fuel consumption of farms by farm size. The relative productive use of fuel by farm size can be obtained by comparing percent of farm fuel purchases with the percentage contribution to agricultural production for each size farm,[1] as shown in Table 6.

Table 6

RELATIONSHIP OF FARM SIZE TO FUEL USE, 1954

Farm Size	Percent of All Farms	Average Value of Sales per Farm	Percent of All Farm Fuel Purchases	Percent of Value of All Farm Sales	Productivity (%Farm Sales : % Fuel Purchases)
Large	12%	$10,000 and over	34%	58%	1.7%
Medium	48	$1,200 - 9,999	48	38	0.8
Small	40	Under $1,200	18	4	0.2

The comparison reveals small farms to be one-tenth as productive as large farms in the use of petroleum fuel, and medium farms to be significantly less productive than large farms. Even though much of the high relative consumption of petroleum on smaller farms can be accounted for by passenger vehicle rather than farm vehicle operation and by other factors such as type of crop and degree of mechanization, the large farm still might command priority treatment should postattack shortages require rationing.

Table 7 shows how petroleum fuels are used on the farm, including household and automobile uses. Perhaps the most significant fact is that the amount of gasoline used for motor fuel greatly exceeds the combined amounts of all other fuels for all other uses. Because of this and the fact that gasoline is more difficult to produce than most other petroleum

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[1] Farmers' Expenditures for Motor Vehicles and Machinery with Related Data, 1955, Statistical Bulletin No. 243, U.S. Dept. of Agriculture, Washington, D.C., March 1959, pp. 10 and 96.

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fuels, the subsequent discussion will be based on considerations of post-attack gasoline storage and production.

Table 7

DISTRIBUTION OF FARM PETROLEUM PURCHASES
BY FUEL AND USE, 1955

Fuel	Motor Fuel (auto, truck, tractor, etc.)	House-hold Use	Poultry or Live-stock	Drying and Cur-ing Crops	Others	All Uses
Gasoline	81%	--	--	--	--	81%
Fuel Oil	--	5%	--	--	1%	6
Diesel Fuel	2	--	--	--	--	2
Tractor Fuel	1	--	--	--	--	1
Kerosene	--	1	1%	1%	--	3
LPG	2	5	--	--	--	7
Total	86%	11%	1%	1%	1%	100%

Source: U.S. Dept. of Agriculture, Farmers' Expenditures for Motor Vehicles and Machinery, op. cit., p. 95.

Two questions regarding gasoline shortage are relevant: what are the capacities and fuel inventories of gasoline bulk plants and distributing terminals in rural areas; and what is the farm storage capacity and inventory. A third question is related to the expected quantities of gasoline that can be produced postattack. Discussion of all three of these questions follows.

Rural Bulk Storage

Bulk fuel stocks in urban areas and service stations cannot be considered as an agricultural fuel reserve, because they would in all probability be unavailable for strictly farm use. However, many wholesale

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bulk plants and distributing terminals are located away from large cities. If it can be assumed that bulk plants and terminals that are located in places of less than 5,000 population are essentially rural (or at least are located away from centers of attack damage and can be considered to be potentially available for postattack agriculture), then the rural gasoline bulk storage capacity and inventory can be estimated.

Table 8 develops the 1954 estimate of rural bulk storage capacity as 1,550 million gallons--29 percent of the U.S. total. If it is assumed that normal inventories are 50 percent of capacity,[1] then 775 million gallons of gasoline could be potentially available to postattack agriculture. On a 1954 per farm basis there would be 160 gallons of gasoline for each farm. The number of farms has declined since 1954 and it is likely that the gasoline bulk storage capacity has increased; therefore, the estimate of 160 gallons of gasoline per farm can be regarded as conservative, both presently and in 1965.

Since the 40 percent of U.S. farms categorized as small accounted for only 4 percent of the total value of agricultural production in 1954, there is good reason to eliminate this group from the estimate. The resulting estimate of rural bulk inventory is increased to 270 gallons per farm. Prorated on the basis of normal farm use, the bulk inventory would supply 450 gallons per large farm and 225 gallons per medium farm.

Farm Storage

Although nationwide data on storage capacities and inventories of gasoline on the farm are not available, Table 9 shows the gasoline storage capacity for a sample of Midwest farms. In the area represented by this sample, farming is intensive.[2] The results of the survey have been extended to give estimates of gasoline storage capacity by farm size.[2]

1/ Representatives of a large western oil company have stated that 50 percent is a realistic figure.

2/ In 1953 farms in this area used an average of 2,000 gallons of motor fuel compared with only 1,420 gallons nationally, even though the 256-acre farm average in these states was about the same as the 242-acre U.S. average. Statistical Abstract of the United States: 1957, U.S. Bureau of the Census, Washington, D.C., 1957, p. 619; and Liquid Petroleum Fuel Consumption for Farm Purposes, Statistical Bulletin No. 188, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, D.C., July 1956, p. 14.

Table 8

U.S. GASOLINE BULK PLANTS AND TERMINALS, 1954

(1) Facility Size (thousands of gallons)	(2) Estimated Number of Employees	(3) Number of Establishments		(4) Estimated Mean Storage Capacity (thousands of gallons)	Total Capacity (Col. 3 x 4) (thousands of gallons)	
		In All Areas	In Rural Areas[1]		In All Areas	In Rural Areas[1]
0-41	1-3	20,365	14,388	26	530,000	370,000
42-62	4-7	4,487	2,248	51	230,000	110,000
63-209	8-19	2,419	930	160	390,000	150,000
210-3,149	20-49	746	228	2,000	1,500,000	340,000
3,150-6,300 and Over	50+	302	64	9,000	2,700,000	580,000
Total		28,319	17,858		5,350,000[2]	1,550,000

1/ Places of less than 5,000 population.
2/ Actual total space assigned to gasoline for the United States was 5,365,588,000 gallons or 0.3 percent greater than that computed by the estimating procedure.

Source: Derived by Stanford Research Institute from data of Bureau of the Census, which reports number of establishments by number of employees, 1954 Census of Business, Vol. III, "Wholesale Trade, Petroleum Bulk Plants and Terminals," Washington, D.C.

Table 9

GASOLINE STORAGE CAPACITY ON MIDWEST FARMS,[1/] 1957

Tank Size (gallons)		Percent of Total Farms Reported	Estimated Grouping by Farm Size	Average Storage Capacity by Farm Size (gallons)[2/]
Range	Mean			
0-20	10	0.2%	Small	
21-40	30	0.3	Small	50
41-70	55	5.5	Small	
71-150	110	17.3	Medium	
151-400	275	54.9	Medium	240
401-700	550	15.6	Large	
Over 700	1,000	6.2	Large	680

1/ States represented in the sample are: North Dakota, South
Dakota, Nebraska, Minnesota, Iowa, Wisconsin, Illinois, and
Indiana. The scale of farming operations in these states
is intensive.

2/ One way to estimate capacity by farm size would be to assume
that the reporting farms are divided into small, medium, and
large farms in the same proportion (40, 48, and 12 percent)
as are all farms in the United States. However, to consider
this sample of farm journal subscribers representative would
be inappropriate, because these subscribers constitute a
population that is probably biased in favor of the large and
medium farms, and the bias would be reinforced if responses
were more often obtained from the large and medium farms.
Therefore, rather than use the national relationships, the
procedure adopted was to assign capacity on a basis that
yielded sensible storage capacity by farm size (as obtained
from the extended survey results) to actual 1955 farm deliv-
eries (obtained from pp. 80 and 96 of Farmer's Expenditures
for Motor Vehicles and Machinery). The decimal fractions of
farm storage capacity to gasoline delivery for the assign-
ment shown in the table are: small farms, 0.28; medium
farms, 0.21; and large farms, 0.23.

Sources: First three columns: Petroleum Products Survey, 1957,
Midwest Farm Paper Unit, Inc., Chicago, Illinois, 1957,
p. 28, based on 5,180 replies from farmers subscribing
to a farm journal. The source reports the gasoline as
inventory rather than capacity but a private communi-
cation from C. P. Mathias, Warren Petroleum Corporation,
Tulsa, Oklahoma, states that the units are actually
capacity. Last two columns: Stanford Research In-
stitute.

An over-all average gasoline storage capacity of 220 gallons per farm is obtained by applying the estimated capacity by farm size to the nationwide percentages of small, medium, and large farms. If the assumption that normal inventories amount to 50 percent of capacity is realistic, then the average amount of gasoline stored on a typical farm would be 110 gallons. Broken down by size category, average inventories would be: small farms, 25 gallons; medium farms, 120 gallons; large farms, 340 gallons. Seasonal variation in favor of larger inventories in the cultivating and harvesting months can be expected.

Postattack Gasoline Production

Postattack production of gasoline has been discussed and evaluated in detail in a recent SRI report.[1] The findings are not repeated here, and for consistency within the present report, a new evaluation of postattack production is carried out by the procedure developed in Chapter II. This method considers the fraction of gasoline production capacity receiving less than 3,000 r/hr at H plus 1 hr as the measure of surviving productive refining capacity. Even though some plants would remain physically undamaged in contaminated areas of more than 3,000 r/hr, the limit is operationally meaningful since population losses are so extensive in the heavier attacks that there is little likelihood that the economy could transfer surviving workers from other occupations to refinery operations. Moreover, even for the lighter attacks after which adequate numbers of people would be available for transfer to refinery operations, extensive training would be required before these people could be usefully employed in the specialized operations of an oil refinery. The estimates of percentage of normal production in the first postattack year given in Table 10 are based on the 3,000 r/hr limitation.[2]

Another possible attack pattern might be specifically directed against petroleum refineries, in the manner found successful against German oil and chemical production in World War II. The effects of use of nuclear weapons in such an attack in the early 1960's was analyzed in another SRI report,[3] and the resultant first-year postattack gasoline

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1/ The Effects of Nuclear Attack on the Petroleum Industry, Stanford Research Institute, July 1960.
2/ Attack Damage Digest, Stanford Research Institute, December 1959, revised April 1961, Figure VI-2. SECRET, RESTRICTED DATA.
3/ Stanford Research Institute, The Effects of Nuclear Attacks on the Petroleum Industry, op. cit., p. 15.

production was estimated at 7 percent of normal. Production after the
first year could be increased by development of primitive refining facili-
ties and other adaptations. However, an attack disrupting oil production
even temporarily would create many individual bottlenecks in agriculture,
as well as in other sectors of the economy. These problems are discussed
in the report just referred to.

Table 10

GASOLINE PRODUCTION IN FIRST POSTATTACK YEAR

Early 1960's Attacks

Military	96%
Military-Population	65

Late 1960's Attacks

Military	62%
Military-Population	21

Vulnerability Summary

Rural bulk storage space assigned to gasoline has been estimated at
450 gallons for the average medium farm and 900 gallons for the average
large farm; average farm storage capacity for gasoline has been estimated
at 240 gallons for medium farms and 680 gallons for large farms. Assum-
ing normal inventories to be 50 percent of storage capacity, the total
gasoline available would be: medium farms, 350 gallons; large farms,
790 gallons. As a percentage of total 1955 gasoline purchases, this
would provide large farms with 21 percent of their normal annual use and
medium farms with 19 percent.

Assuming that essentially all of these stocks would survive an at-
tack, sufficient gasoline should exist on farms and in rural bulk stor-
age tanks to permit most large and medium farms to maintain normal op-
erations from two to three months postattack. After this, supplies would
have to be renewed from outside sources.

Postattack production of gasoline should be adequate to meet essen-
tial production needs following either of the military attacks as well
as the early 1960's military-population attack. However, heavy losses

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would be sustained where refineries are targeted separately, as well as after the late 1960's attack on population centers. In view of the large contribution to production provided by mechanized farming, a high fuel priority for agriculture would seem warranted following these attacks. Since farms purchased only 14 percent of the refinery production of gasoline in 1955,[1] some diversion from other uses to agricultural purposes would by no means exhaust the gasoline supplies.

However, even with a pro rata allocation of postattack production, availability of gasoline for farming (including 20 percent of a year's supply in farm and local storage) would in general be enough to sustain a significant fraction of normal operations. Total farm fuel availability in the first postattack year, obtained by adding the 20 percent stored local stocks to the production estimates of Table 6, would be as shown in Figure 9.

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[1] Including automobile supplies, U.S. Dept. of Agriculture, Farmers' Expenditures for Motor Vehicles and Machinery, op. cit., p. 96.

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FIG. 8
FARM PETROLEUM AVAILABLE IN FIRST POSTATTACK YEAR

EARLY 1960s
MILITARY ATTACK — 100

EARLY 1960s MIL.-
POP. ATTACK — 85

LATE 1960s
MILITARY ATTACK — 82

LATE 1960s MIL.-
POP. ATTACK — 41

PERCENT OF PREATTACK

0   20   40   60   80   100
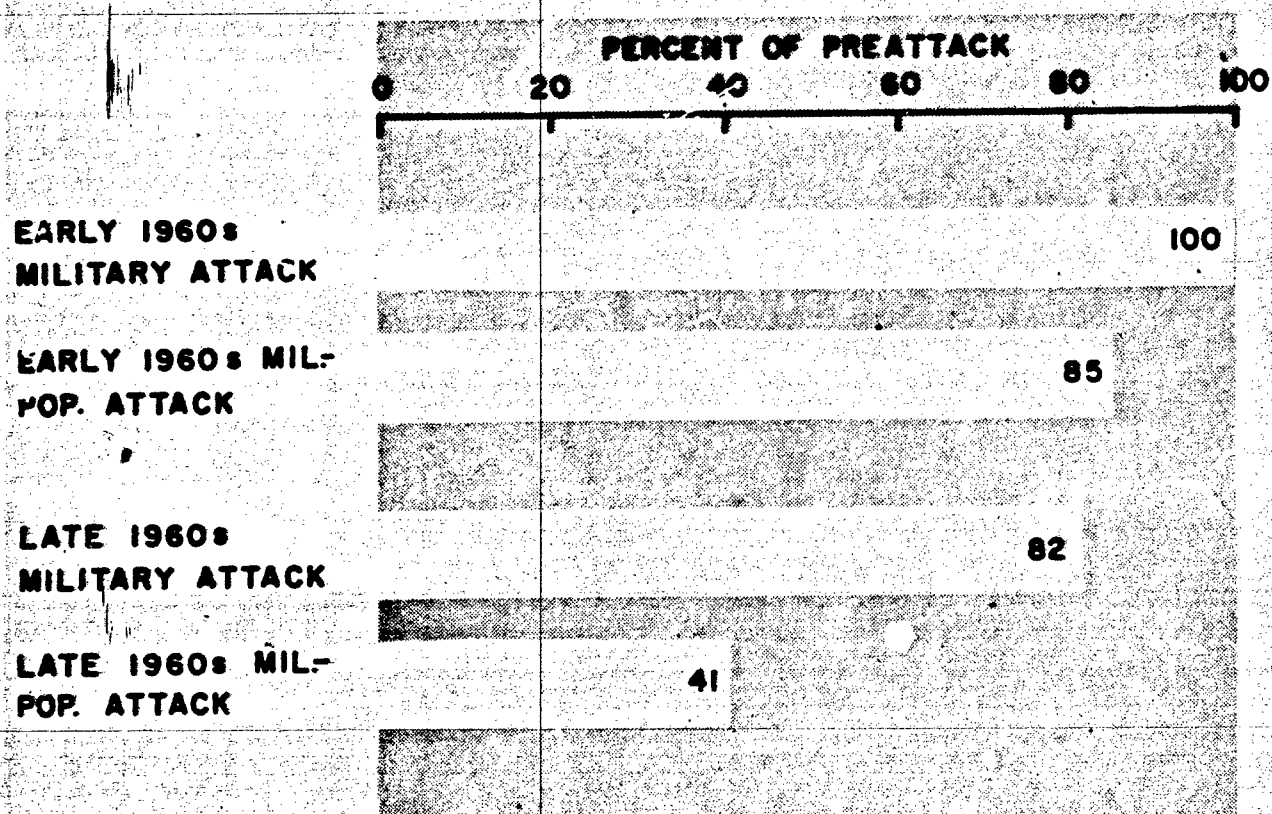
PRODUCTION

NEW MACHINERY

PARTS
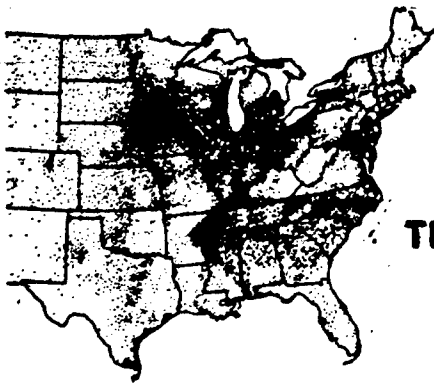
TRACTORS

EQUIPMENT

DISTRIBUTION
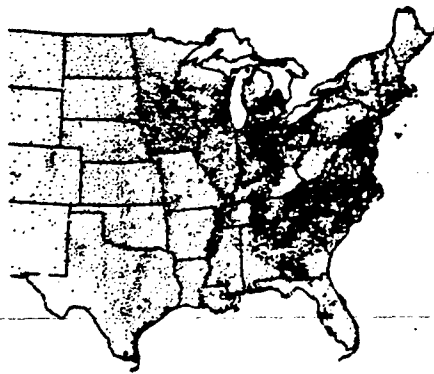
AUTOS

TRUCKS

COMBINES

OTHER
FARM
EQUIPMENT
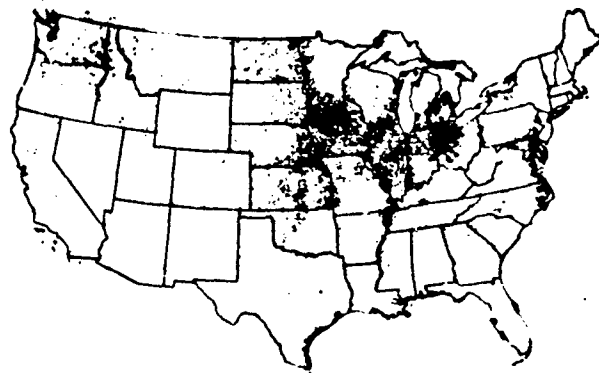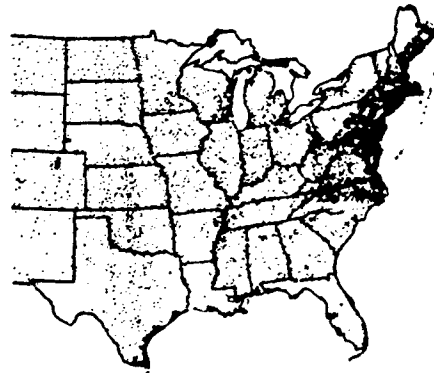
Chapter VI

EQUIPMENT

Between 1940 and 1957, output of agricultural products per man-hour doubled. Much of this increase can be attributed to the mechanization of farm production.[1] Of the farms reporting tractors in 1954, 78 percent had two; 7.5 percent had three; 2.0 percent had four; and 1.4 percent had five or more.[2] It is, therefore, encouraging that farm equipment located on farms would suffer insignificant damage from any of the postulated attacks. In general, the farming areas are away from target centers and hence would not be subject to blast effects. Farm equipment, if exposed, does offer a surface for fallout to be deposited, but where the fallout levels are not so heavy as to incapacitate the rural population, the equipment can be put back into use after decontamination. Where fallout levels are lethal, the equipment may deteriorate because of lack of use, but farming in such areas would be denied anyway by manpower losses and land contamination. Losses sustained by equipment on farms are therefore not likely to act as a constraint to postattack agricultural production.

Equipment would, of course, require repair and maintenance, and, under normal conditions, new parts and equipment would have to be purchased to replace old. However, during the immediate postattack recovery period, new parts and equipment would not be essential because there is a large amount of equipment located on farms, it has a long life, and its attack losses are probably the smallest of any vital input (including manpower and land).

The apparent service life of farm equipment varies from less than 10 years for certain types of harvesting machines, to 16 years for tractors, and 20 years or more for some planting machines.[3] Length of effective useful life is difficult to estimate, but it probably has tended

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1/ Bishop, C. E. and W. D. Toussaint, *Agricultural Economics Analysis*, John Wiley and Sons, Inc., New York, 1958, pp. 228-229.

2/ *1954 Census of Agriculture*, Vol. II, U.S. Bureau of the Census, Washington, D.C., Chapter III, pp. 218-219.

3/ *Farm Machinery*, Statistical Bulletin No. 269, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, D.C., October 1960, Table 25.

to increase; newer tractors for example may last as long as 20 years.[1]/
An example of equipment age distribution is that of wheel tractors on
farms in January 1956: 34 percent had been manufactured within the pre-
vious 5-year period while 35 percent were 5 to 10 years old.[2]/ Trucks
showed a similar pattern.[3]/

The relatively long life of farm equipment is partially explained
by its low annual use. Tractors receive perhaps the highest use; the
average annual use (in 1955) per tractor kept on farms was about 560
hours[4]/ (70 eight-hour days). Field machines (exclusive of tractors,
trucks, and wagons) seldom receive annual use in excess of 15 days;
balers, combines, and corn pickers may be operated 20 or 30 days per year.
Planting equipment generally is not needed more than 4 or 5 days a year.[5]/

Much of the older equipment is used even less frequently; for ex-
ample, some old tractors are used only a few hours during the year.[6]/
This indicates that equipment tends to become obsolete faster than it
wears out, and that many farmers retain old equipment rather than junk
or sell it. Although older machines could not be depended upon for
continuous use and are not adaptable to much of the newer accessory
equipment, they are serviceable for at least brief periods and would al-
leviate postattack shortages of repair parts and services. Cooperative
arrangements between farms could also be made where necessary to offset
equipment failures, particularly where similar cooperation is normally
practiced in work by custom operators.

The possibility of interchanging standard or semistandard parts be-
tween different farm vehicles should also be recognized. Items such as
spark plugs and batteries could in some cases be switched from the less
important to the more important farm vehicles. This interchange could

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1/ _Ibid_, p. 27.
2/ _Farmers' Expenditures for Motor Vehicles and Machinery with Related
Data, 1955_, Statistical Bulletin No. 243, U.S. Dept. of Agriculture,
Washington, D.C., March 1959, p. 57.
3/ _Ibid._, p. 31.
4/ _Ibid._, p. 6.
5/ Bainer, Kipner, and Barger, _Principles of Farm Machinery_, John Wiley
and Sons, Inc., New York, 1955, p. 33.
6/ _Numbers of Selected Machines and Equipment on Farms with Related
Data_, Statistical Bulletin No. 258, U.S. Dept. of Agriculture, Wash-
ington, D.C., February 1960, p. 5.

be extended to include tires, tubes, and common bearings among those machines with matching parts. Occasionally, the farmer in his own repair shop or at a rural equipment repair outlet would be able to devise temporary expedients to handle unique requirements. At other times, he would have to resort to farm machinery suppliers, or possibly even the manufacturer.

For the most part, these means should satisfy the demands for special parts following attacks limited to military targets. However, a dependable supply could not be expected after attacks directed at population targets. Manufacturers of farm machinery, tires, and other mechanical parts would be relatively vulnerable to population attacks. No calculation has been made of losses of farm machinery workers, but an estimate of losses among workers in the entire non-electrical machinery industry is summarized in Figure 9. This estimate is considered in the present analysis to reflect ability to produce new farm equipment.

Even in the case of heavy losses to the production of new equipment, the postattack ratio of farm equipment to other farm inputs would probably increase. Therefore, postattack agricultural production should not be limited by a lack of new equipment, except in the case of short-lived and hard-to-get items. Essentially all necessary equipment for available workers and land should be usable in the first year under all four postulated attacks.

FIG. 9
NON-ELECTRICAL MACHINERY MANUFACTURING PERSONNEL
AVAILABLE FOR WORK IN FIRST POSTATTACK YEAR

PERCENT OF PREATTACK

0	20	40	60	80	100

EARLY 1960s
MILITARY ATTACK — 95

EARLY 1960s MIL.-
POP. ATTACK — 30

LATE 1960s
MILITARY ATTACK — 78

LATE 1960s MIL.-
POP. ATTACK — 19

WEST EAST

PRODUCTION

BILLION KWH

51
380
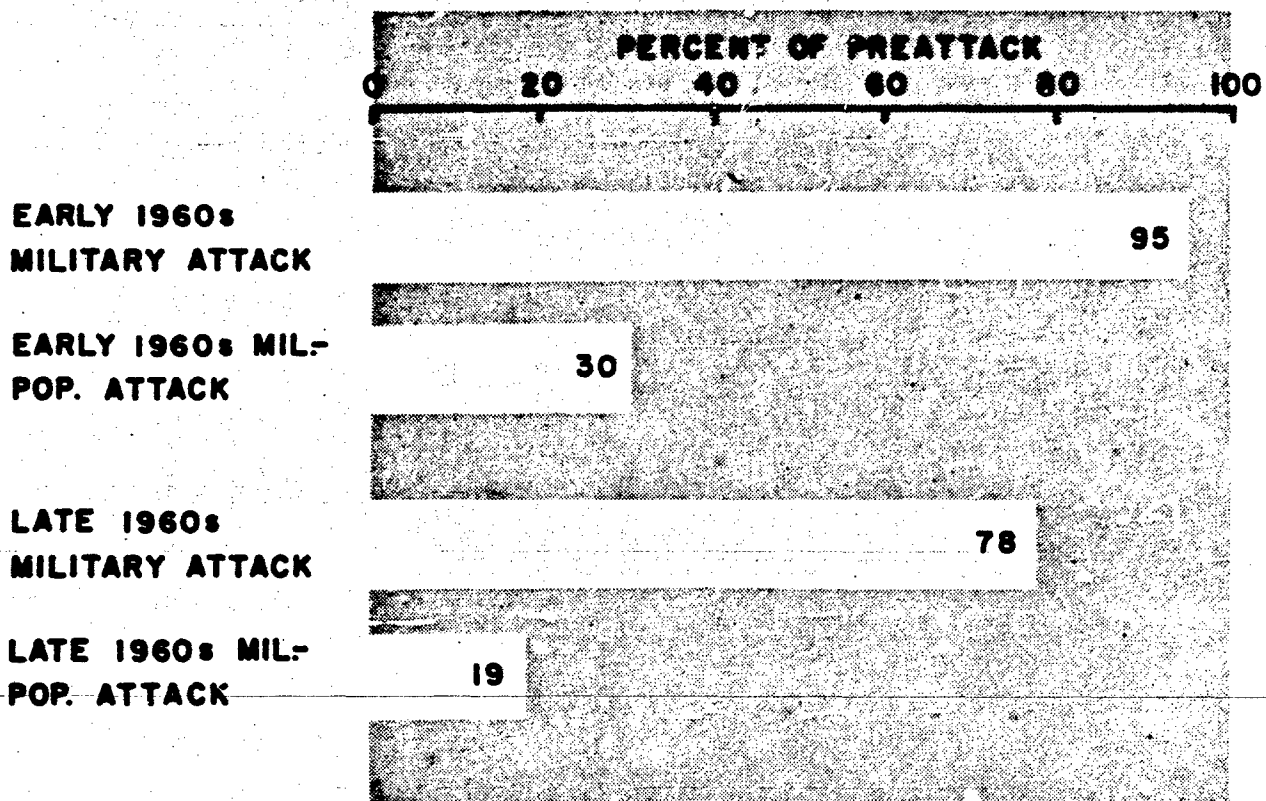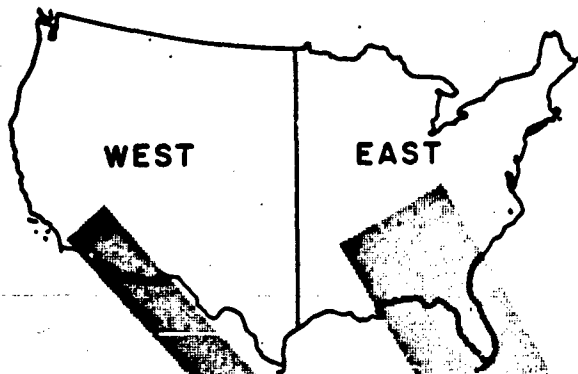
HYDRO
STEAM

ELECTRICITY

DISTRIBUTION

IRRIGATION

FARM USES

MILKING

STORAGE

HATCHING

PROCESSING

WORKSHOPS

NONFARM
USES

Chapter VII

ELECTRICITY

Background

The review of the electric power industry that follows is a cursory one since the object of this chapter is to highlight only the more obvious aspects of attack vulnerability of electric power generation and transmission as they are related to farm power supplied.

Electric power generating plants are of three types: hydroelectric, steam, and internal combustion. Of the total 1958 power generated by the nation's electric utilities, hydroelectric plants provided about 20 percent; steam plants, 79 percent; and internal combustion plants, 1 percent (so small a fraction that this last source will not be considered). Hydroelectric generation is greatest in the Mountain and Pacific States, where in some areas it greatly exceeds steam generation. In 1957 Washington, Oregon, and California accounted for 45 percent of the hydroelectric power generated in the United States.[1]

The electric utilities are the major producers of electricity; in 1958 they generated 645 billion kilowatt hours or about 89 percent of the total.[2] Industrial plants accounted for the remaining 11 percent. Home generating units have disappeared from all but the most remote areas, as reliable electric service has been extended.[3]

Power is transmitted from the generating station to load centers on high voltage lines, which also serve to interconnect one system with another for purposes of balancing peak loads or for emergency reasons.

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[1] Statistical Abstract of the United States: 1959, U.S. Bureau of the Census, Washington, D.C., p. 529.

[2] Federal Power Commission, 39th Annual Report, Washington, D.C., pp. 30-31.

[3] In early 1960 only 23,500 (0.5 percent) of the farms in the United States were served by home lighting plants. Electric Utility Industry Statistics in the United States for 1959, Edison Electric Institute, September 1960, p. 70.

Economical transmission of power is accomplished by using high voltages in the transmission lines, but safety and convenience require that the voltage be stepped down in stages before it reaches the consumer.

Consumption of electric power by type of consumer in 1955 is shown in Table 11. That the farm is a relatively small user of electricity is readily apparent, and almost a third of its total use is for irrigation. Annual consumption of irrigation power per farm is much higher west of the 100th meridian[1] than in the East: an average of 8,435 kwh as opposed to 4,428 kwh in 1958.[2] Irrigation power is discussed in Chapter VIII.

Excluding irrigation requirements, most of the power used on farms operates household rather than farm equipment. In a study of farm uses of electricity largely limited to areas east of the Rocky Mountains, the Department of Agriculture found that equipment used in farming operations required only 3 to 30 percent of total electric power consumed on the farm, with dairying and poultry producing areas requiring the most.[3] Another more recent estimate of farm consumption of electric power was 80 percent for household use and 20 percent for equipment outside the home.[4] Although the use of electricity per farm is expected to increase in the future, including more non-household applications, the over-all rate of increased use for farms in the United States will not be as large as that for other classes of use.[5]

Process Description

1. Generation--Hydroelectric

Hydroelectric power generation requires both pressure (or "head") and flow. Efficient pressures and flow rates are usually obtained by

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1/ The 100th meridian passes from the Dakotas through western Texas.
2/ *Farm Electrification*, Edison Electric Institute, July-August, 1959.
3/ *Use of Electricity on Farms*, Agricultural Information Bulletin No. 161, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, D.C., November 1956, p. 26.
4/ McDonald, Thomas R., Dean B. Price, and Harry W. Thiesfeld, "Rural Distribution Transformer Loading," *Power Apparatus and Systems*, June 1959, p. 301.
5/ *Estimated Future Power Requirements of the United States by Regions, 1955-1980*, Federal Power Commission, Washington, D.C., December 1956, p. 10.

Table 11

CONSUMPTION OF ELECTRIC POWER FROM UTILITY SYSTEMS[1]
1955

Type of User	Percent of Total
Farm (exclusive of irrigation)	3.6%
Irrigation and Drainage	1.6
Non-Farm Residential	22.0
Commercial	16.0
Industrial[2]	52.0
Other	4.8
Total	100.0%

[1] Exclusive of energy losses and unaccounted power.

[2] Taking account of the power generated by industrial plants themselves would raise the percentage consumed by industrial users to 58 percent.

Source: Estimated Future Requirements of the United States by Regions, 1955-1956, Federal Power Commission, December 1956, p. 17.

building dams in sizable streams.[1] Water under pressure moves the turbine located at the base of the dam; the turbine drives an electric generator. Of course, the total force delivered depends not only on the pressure but also on the flow. It is this flow requirement that makes many hydroelectric plants operable during only seasons of the year when water is abundantly available.

Hydroelectric installations have the advantage of being able to store water for future needs, whereas electricity itself cannot be economically stored. Often, therefore, hydroelectric plants are used to support steam plants during periods of peak demand and are permitted to stand idle much of the rest of the time. Moreover, by use of automatic control and switching equipment, it is possible to operate hydroelectric installations almost entirely without attention.[2]

2. Generation--Steam

Steam plants utilize the expansive energy of superheated steam to drive turbines and generate electricity. Different fuels are used in different regions, but on a national basis coal supplies 68 percent of the fuel used in these operations; natural gas, 24 percent; and oil, 8 percent.[3] Steam plant sites are determined by the location of the power demand, the type and location of the fuel supply, and the availability of adequate water. Not only are large quantities of pure water needed for conversion to steam in the boilers, but much larger volumes of cooling water are needed for condensing purposes.[4]

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[1] Also natural pressure heads can be utilized; e.g., at Niagara Falls some of the water is diverted from above the falls to drive the generators located at the base.

[2] Glover, John G., and Rudolph L. Lagai, The Development of American Industries, 4th edition, Simmons-Boardman Publishing Company, New York, 1959, p. 520. Officials at Pacific Gas and Electric Company stated that as of January 1, 1959, almost all of their hydroelectric installations (which represented 37 percent of their entire capacity) were fully automatic. The remaining few are expected to be fully automatic before 1965.

[3] Federal Power Commission, Estimated Future Power Requirements of the United States, op. cit., p. 28.

[4] Glover and Lagai, The Development of American Industries, op. cit., pp. 522-523.

3. Transmission

The electricity produced at the generator is stepped up with a transformer to higher voltages for more efficient transmission. At present the practical limit for sending electricity is about 300 miles.[1] As the power feeds out from the main transmission line through the distribution system it is stepped back down. Transformers at substations typically reduce the transmission line voltage to a few thousand volts before sending it out through the distribution system. It is usually reduced to 120 or 240 volts by a smaller transformer located near the customer.

Extensive interconnections between power systems have been developed. They reduce the spare generating plant needed to meet breakdowns, allow the system to meet varying peak loads, and permit initial use of the lowest cost electricity from each station. In some areas, automatic switching installations have been built to furnish additional electricity or to maintain continuing supplies where power is lost.

Vulnerability Assessment

1. Vulnerability of Generating Stations

While blast effects will account for part of the losses to generating stations, plant manpower losses from radiation effects will be a critical factor in determining effective surviving postattack generating capacity. Although generating stations normally require only small crews, and some hydroelectric stations are completely automatic, some human maintenance and control is required. Therefore, in the present analysis, all plants destroyed, seriously damaged, or receiving over 3,000 r/hr are considered out of production during the first year. This assumption requires that personnel have good fallout shelter (such as in large buildings or a prepared basement area) and that working areas be decontaminated. However, it also implies that major repairs to damaged

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[1] The Hoover Dam to Los Angeles line distance is 278 miles. A line voltage of 345,000 volts, currently the highest in the United States, is used for this transmission. Glover and Lagai, op. cit., p. 525.

installations cannot be made in time to resume generation within the first year and that replacement personnel from uncontaminated areas will not be available to enter and operate contaminated facilities. The estimated percentages of undamaged generating capacity in radiation zones receiving less than 3,000 r/hr are given in Table 12.

Table 12

GENERATING CAPACITY IN FIRST POSTATTACK YEAR

Early 1960's Attacks

Military	99%
Military-Population	62

Late 1960's Attacks

Military	79
Military-Population	38

2. Vulnerability of Transformer and Transmission Facilities

In World War II distribution facilities proved to be less of a bottleneck under bombing attacks than generating stations, although this vulnerability relationship cannot necessarily be extrapolated to nuclear warfare.[1] Many World War II bombs were aimed at generating stations or at industrial areas where generating stations were located, and damage was quite limited in most cases, whereas with the large-area coverage of nuclear weapons, extensive portions of the distribution networks could be destroyed as well. But even under nuclear attacks, the great number of electric power lines and the interconnections between systems provide a series of alternative distribution paths. Unfortunately, interconnections are not as well placed as they could be,[2] but they do add considerable flexibility to offset losses of generating capacity.

1/ Loeb, Benjamin S., Electric Power Supply and National Security, AECU-4642, Atomic Energy Commission, Washington 25, D.C., 1959, Chapter XII.
2/ Ibid., Chapter XIV.

Transformers are the critical link in the distribution system.
Loss of these vital substation installations can leave an area without
power for an extensive period postattack, but damage to transmission
lines can be repaired relatively easily once the damaged area is safe
for the crews to enter. The estimated transformer capacity surviving in
the United States following each of the attacks is shown in Table 13.
Losses are assumed to be from physical destruction only, since fallout
does not significantly affect substation operations.

Table 13

TRANSFORMER CAPACITY IN FIRST POSTATTACK YEAR

Early 1960's Attacks

Military	98%
Military-Population	56

Late 1960's Attacks

Military	91
Military-Population	44

Transformer losses are seen to be quite similar to generation sta-
tion losses. They might increase the over-all system losses if power
were needed in an area served by a damaged transformer and rerouting
through local interconnections were not feasible, but electrical demand
in such damaged areas would probably not be great.

Repairs could be made to transmission facilities (except transformers)
by regular repair crews. Since many of these crews would be located in
rural areas, survival rates would be relatively high. Local distribution
could be a problem in areas suffering both damage and repair crew casual-
ties, but given time, crews from other areas could be moved in. Over-all
electrical system losses would probably not be seriously constrained by
distribution system losses, particularly in rural areas.

3. Vulnerability of Fuel Supplies

In 1958 fuel requirements of electric utility steam generating sta-
tions were 156 million tons of coal, 1,373 trillion cubic feet of gas,

73

and 78 million barrels of oil.[1] The percentage of available workers in the petroleum and coal industries is taken in this analysis as indicating surviving capacity. Again, available fallout protection equivalent to that of a home basement is assumed. On this basis, postattack fuel production capacity would be as shown in Table 14.[2]

Table 14

FUEL PRODUCTION IN FIRST POSTATTACK YEAR

Early 1960's Attacks

Military	94%
Military-Population	24

Late 1960's Attacks

Military	77
Military-Population	14

If substantial reserve fuel stocks were not locally available to thermal plants, fuel shortages could well be constraining after either of the attacks directed at population centers. Coal production is particularly important in the East, both because coal is the most common fuel for electric power, and because electric utilities are the largest users of coal. (They consumed 30 percent of all coal produced in the United States in 1957.)[3] Many of the other large users of coal[4] might rate priorities almost as high as electric power plants, so that it is not certain that utilities could be supplied with sufficient fuel to support all surviving generating capacity. Fortunately, the normally large

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1/ Federal Power Commission, Estimated Future Power Requirements of the United States, op. cit., p. 29.

2/ Attack Damage Digest, Stanford Research Institute, December 1959, revised April 1961, p. 296. SECRET, RESTRICTED DATA.

3/ Statistical Abstract of the United States: 1959, U.S. Bureau of the Census, Washington, D.C., 1959, pp. 727-728.

4/ Coke oven plants, using 20 percent of 1957 production, were the next largest consumer. Ibid.

supplies of coal stored by generating stations is an offsetting factor. In 1958 electric power installations usually had over 100 days' supply. These large supplies could probably assure sufficient fuel availability during the first year to sustain power generation at most surviving stations.

The dependence of electric power on fuel oil production would be less critical. In 1957 gas and electric power plants used only 14 percent of the residual fuel oil and less than 1 percent of the distillate fuel oil.[1] Moreover, fuel-oil-fired generating stations ordinarily had almost 100 days' supply of oil.

Gas-fired generating stations used only 13 percent of the natural gas consumed in the United States in 1957, but much of this consumption occurred in western regions, where electricity is an important factor in irrigation and pumping. The West South Central area depends completely on gas for thermal electric power, but it also has the greatest density of interconnected pipelines from local gas fields, and would therefore be least vulnerable to interruptions in gas supply. Other areas with heavy dependence on gas (the West North Central, Mountain, and Pacific regions) have good hydroelectric power reserves (these regions generate more than half their thermal power from gas). The vulnerability of natural gas supplies is discussed in detail in Section 3 of Chapter IX.

Vulnerability Summary

Excess capacity partially offsets the indicated losses to generating plants. In building capacity sufficient to meet peak load demands, generating stations necessarily install capacity that is idle part of the time. On a national basis, the major electric utilities in December 1958 had a combined peak load of 113.5 million kw while available dependable capacity was 141.8 million kw. The reserve of 28.3 million kw represented 25 percent of the peak load. The combined peak load is expected to climb to 153.5 million kw by December 1962, at which time the major utilities expect to have dependable capacity of 182.7 million kw available on a reserve margin of 19 percent.[2]

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1/ Ibid., p. 733.
2/ Federal Power Commission, Estimated Future Power Requirements of the United States, op. cit., p. 30.

Excess capacity, however, is generally the least efficient capacity from the standpoint of fuel and other operating requirements. On-farm substitutes for electric power (use of tractor or other engine power for pumping water, grinding feeds, milking cows, etc.) would also be relatively inefficient in their use of fuel, machinery, and manpower even though they could be valuable as emergency measures.

In any event, excess generating capacity and farm power substitutes are of little benefit if there is insufficient fuel. Unless fuel deliveries were resumed promptly, shortages would be encountered after about 3 months, particularly after attacks aimed at refineries or population centers. Some allowance is made for this in the estimates below of electric power generating capacity available in the first postattack year.

The problem of supplying power after an attack is probably not a limitation because interconnections are extensive. Perhaps areas losing key transformer installations would be without power for a long period but rural areas escaping major attack damage would probably have adequate power distribution if generating facilities survived. Moreover, the farm requirement as a percentage of the national total is so small that if power in even minimal amounts can be provided to rural areas, it should be possible to devise priorities that would provide power for critical farm operations such as milk and poultry production. Requirements and availability of power for irrigation are discussed in detail in Chapter VIII.

On a national basis, postattack availabilities of power are primarily dependent on the vulnerability of generating stations, and secondarily on availability of fuel supplies. Where generating stations and fuel supplies survive relatively well (as in the military attacks), power should be at least proportionately available to necessary farming activities. However, where generating stations and fuel supplies are hard hit (as in the population attacks), power shortages could limit production. The resultant power service to farming areas is estimated in Figure 10.

FIG. 10
ELECTRICITY AVAILABLE TO FARM AREAS IN FIRST POSTATTACK YEAR

PERCENT OF PREATTACK

0   20   40   60   80   100

ARLY 1960s
ILITARY ATTACK
100

ARLY 1960s MIL.—
OP. ATTACK
60

ATE 1960s
IILITARY ATTACK
80

ATE 1960s MIL.—
OP. ATTACK
30

(17 WESTERN STATES)

WEST

EAST

OURCES

IRRIGATION WATER

DISTRIBUTION

ALFALFA HAY

COTTON

RICE

IRRIGATED LAND IN FARMS

ORCHARDS

OTHER IRRIGATION

CONVEYANCE LOSSES
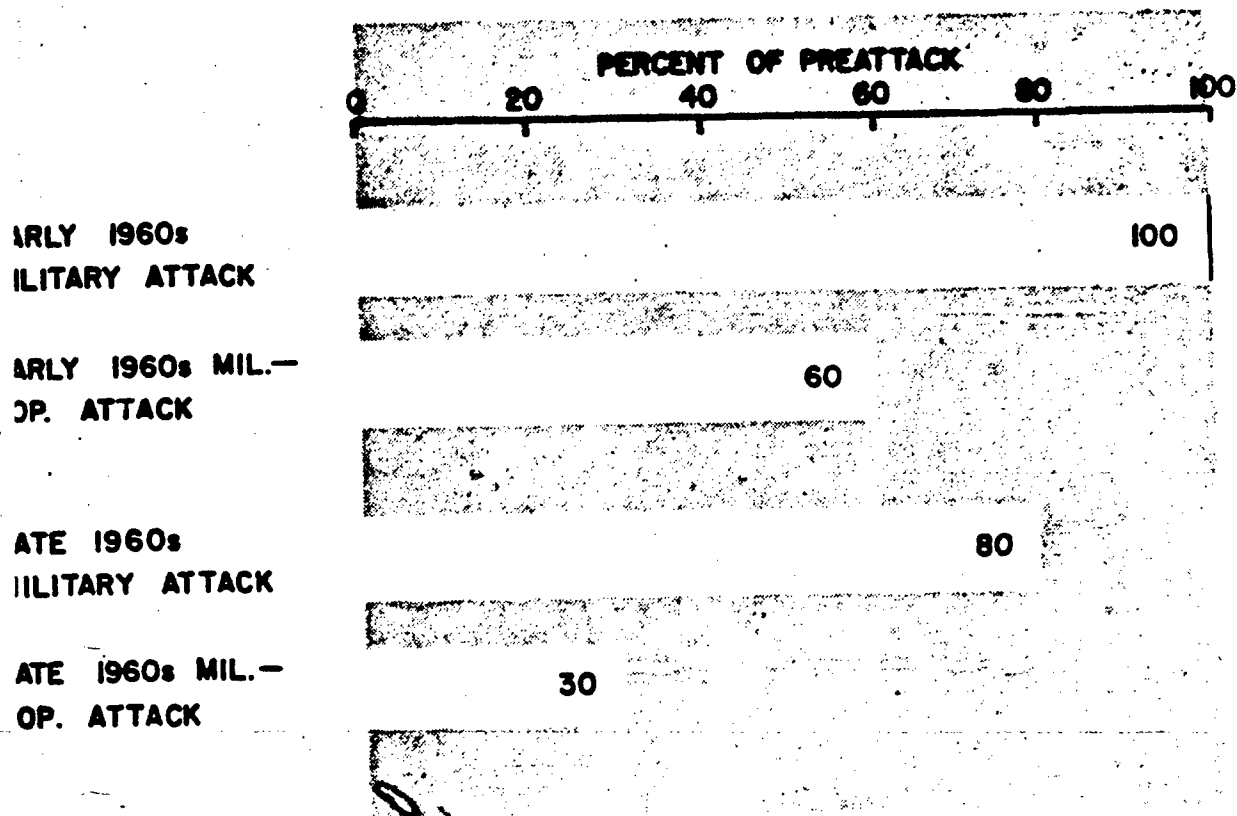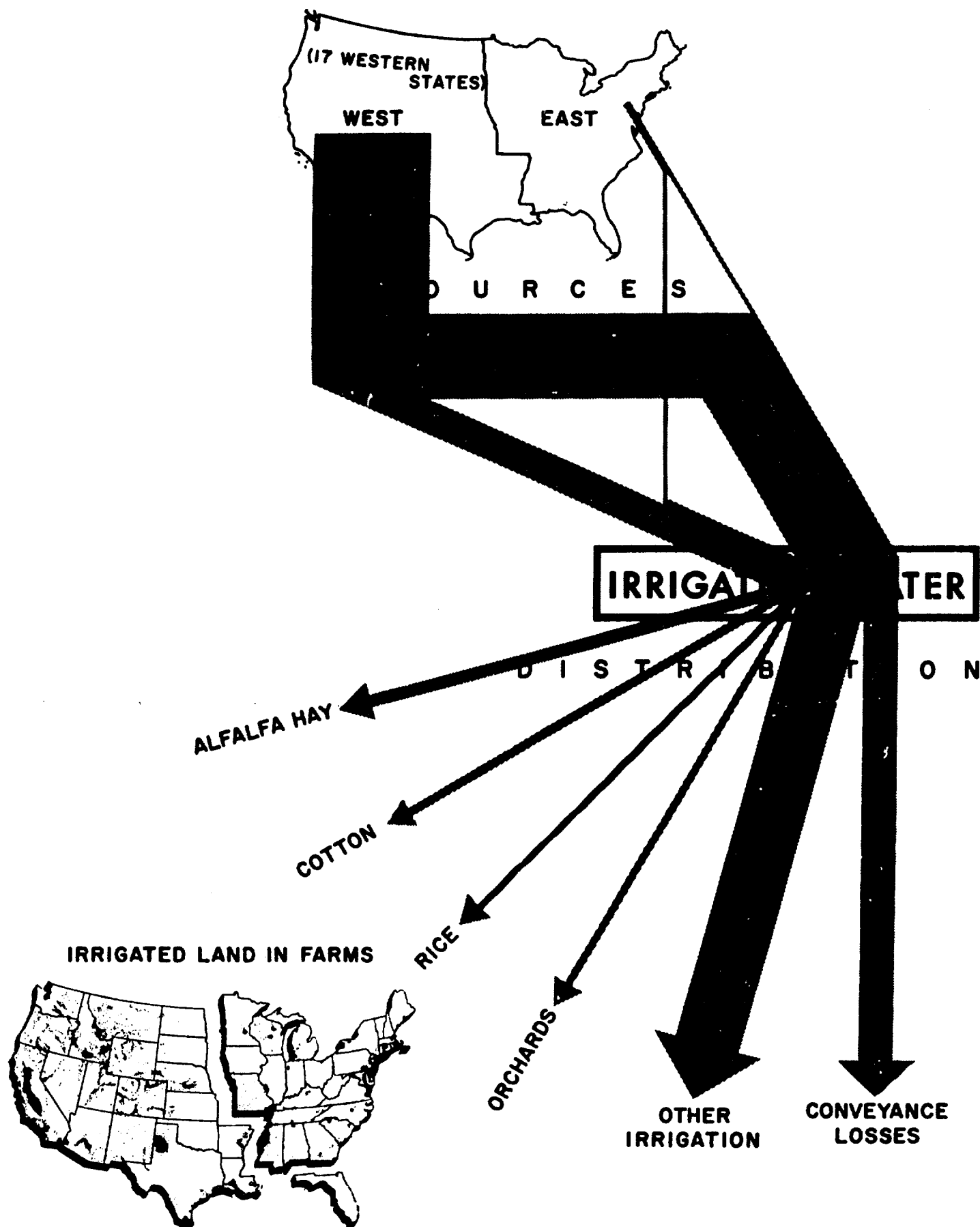
Chapter VIII

IRRIGATION WATER

Background[1]

The quantity of water withdrawn for irrigation is enormous. In 1955 it was as large as the total industrial use of water and 40 times as large as all non-irrigation rural withdrawals.[2]

Although irrigation coverage is large, it is a regional phenomenon: over 80 percent of all water withdrawals in the 17 western states are for irrigation. In 1955 the 17 western states contained 91 percent of the total irrigated land; and Arkansas, Louisiana, and Florida contained 7 percent. Irrigation is particularly intensive in the Mountain and Pacific states, where 56 percent of all farms contained some irrigated land. This does not mean that 56 percent of all farmland in these regions was irrigated, however, for the highest percentage of farmland in irrigation in any state (California) was 18.6 percent.

In most of the major irrigation areas of the West, the irrigation season extends from April to October and the average depth of water applied is almost two feet.[2] In some areas, however, irrigation is required throughout the year and over three feet of water may be applied.

The practice of using supplemental irrigation in humid areas is growing. Here water from wells or from surface supplies is applied to crops during periods of insufficient soil moisture. This is more common

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1/ James E. Collier has described the extent of farm irrigation for the National Atlas of the United States (Irrigated Land, 1954, Bureau of the Census, United States Government Printing Office, Washington, D.C., 1957). Much of what follows describing the general characteristics of irrigation in the United States has been taken from his summary.

2/ MacKichan, Kenneth A., Estimated Use of Water in the United States, 1955, Geological Survey Circular 398, U.S. Dept. of the Interior, Washington, D.C., 1957, p. 13.

with fruits and vegetables than with grains and other field crops, but in any case the proportion of land in humid areas that is irrigated is so small as to be considered negligible in this over-all review of irrigation as an agricultural input.

On the basis of acreage, alfalfa hay was the leading irrigated crop in the 20 major states in 1949, with 3.4 million irrigated acres. Cotton was next with 2.4 million acres; followed by rice, 1.8 million acres; wild hay, 1.7 million acres; and orchards, vineyards, and planted nut trees, 1.6 million acres.[1] Crops most dependent on irrigation are rice, with 100 percent irrigated; sugar beets, 96 percent; hops, 85 percent; dry beans, 83 percent; and Irish potatoes, 78 percent.

Yields on irrigated land average much higher than on non-irrigated land. For example, they are more than double for cotton and barley, and are more than triple for spring wheat and dry beans. These comparisons, however, do not take into account that irrigated and non-irrigated crops may not be grown on land of comparable quality nor under other conditions that are comparable.[2]

Irrigation water is provided both from underground wells and from land surface sources. Table 15 and the ensuing discussion consider the normal and postattack availability of these sources.

Ground Water Supplies

Except for flowing wells (1 percent of the total in the 17 western states in 1950)[3] ground water sources of irrigation water are dependent on a means of power. Windmills to pump water from wells are still found in some areas, but engines powered by electricity, natural gas, gasoline, diesel oil, or other kinds of fuel are more prevalent. In addition, tractors and other auxiliary power sources could be used in some situations, but their extensive use would require large amounts of fuel and might

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1/ "Irrigation of Agricultural Lands," United States Census of Agriculture, 1950, Vol. III, Bureau of the Census, U.S. Government Printing Office, Washington, D.C., 1952, p. 11.

2/ "Irrigation of Agricultural Lands," Bureau of the Census, op. cit., p. 12.

3/ 1950 Census of Agriculture, Vol. III, Bureau of the Census, Washington, D.C., p. 65.

Table 15

ESTIMATED WATER WITHDRAWN FOR IRRIGATION, 1955
(Thousands of Acre Feet per Year)

State	Delivered to Farms				Conveyance Losses	
	Ground Water	Surface Water	Total	Percent of U.S. Total	Ground Water	Surface Water
Arizona	4,400	2,000	6,400	7.0%	880	480
California	8,800	12,000	20,800	22.9	2,400	3,200
Colorado	980	5,000	5,980	6.6	200	1,000
Idaho	1,100	10,000	11,100	12.2	110	5,100
Kansas	680	150	830	0.1	—	—
Montana	110	5,500	5,610	6.2	54	5,300
Nebraska	910	780	1,700	1.9	37	1,200
Nevada	200	1,500	1,700	1.9	33	410
New Mexico	1,200	950	2,150	2.4	300	320
North Dakota	2	80	82	0.1	—	56
Oklahoma	170	61	231	0.3	—	22
Oregon	360	4,100	4,460	4.9	190	3,000
South Dakota	7	18	25	—	1	6
Texas	6,100	3,400	9,500	10.4	1,200	690
Utah	280	3,300	3,580	3.9	26	1,100
Washington	250	2,700	2,950	3.2	2	2,700
Wyoming	26	9,900	9,926	10.9	5	2,000
Total, 17 States	26,575	61,439	88,024	94.9%	5,400	26,586
Arkansas	880	98	978	1.1	3	—
Louisiana	430	540	970	1.1	—	390
Florida	280	270	550	0.6	2	11
Total, 20 States	28,165	62,347	90,522	97.7%	5,446	26,987
Total, United States	29,000	63,000	92,000	100.0%	5,500	27,000

Source: Kenneth A. MacKichan, op. cit., p. 8.

rapidly wear out the equipment. Therefore, auxiliary power sources for irrigation would not be important.

In 1950 there were 100,452 electric motors used for pumping in the 17 western states and 37,258 "other motors and engines used for pumping:"[1] moreover, of the electric motors used, 73,682, or 73 percent, were in California. Among the other states, only Arizona depends largely on electric pumps for supplying irrigation water. Elsewhere, gravity flow or fuel-powered motors and engines dominate.[2] Since the California requirement for irrigation power far exceeds that of Arizona (73,682 vs 3,103 electric motor pumps), attention will be restricted to California.

Except for normal maintenance, the electric motors used to power irrigation pumps are not a problem. Rather, the problem is whether or not continued supplies of electricity can be provided to the pumps in a postattack period. This question was explored with officials of the Pacific Gas and Electric Company,[3] which provides electric power service to the northern two-thirds of California. Their opinion was that electric power would be available to rural areas that could use such power (i.e., that were not blanketed with fallout) shortly after an attack. Where intensive fallout precluded entry by electric repair and maintenance crews, the area would similarly preclude habitation by agricultural workers and hence agricultural demands for electric power in these areas would be nonexistent.

The factors that contributed to this high estimate of continued power service to rural areas were the following:

1. At least 50 of PG&E's 62 hydroelectric generating stations, which represented 37 percent of the company's capacity on January 1, 1959, are fully automatic at present and the remainder are expected to be converted to automatic operation before 1965. Except for a near hit, then, the hydroelectric plants would be almost unaffected by the attacks and could continue in operation despite heavy fallout.

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[1] Bureau of the Census, op. cit.
[2] Ibid., p. 62.
[3] Mr. T. Harold Anderson, Vice President and Assistant General Manager; Mr. A. J. Swank, Vice President in Charge of Electric Operations.

Since steam plants depend on fuel supplies and are less automatic, they would be somewhat more vulnerable to fallout or a breakdown in the economy (see Chapter VI). Little auxiliary generating equipment on farms or other private installations apparently exists in the PG&E service area; therefore, auxiliary power cannot be considered an important source of postattack irrigation power supply.

2. The PG&E hydroelectric plants are strung along PG&E's entire system, beginning with the Cascade Mountains in the north and stretching southward along the Sierra Nevada. The plants are not only well dispersed but in general are also remotely located so that they make a poor target. Furthermore, since they are spread out along the entire system, individual hydroelectric generating stations are local to most agricultural areas (although they may be supplemented by power from the large coastal steam plants or from a particularly large hydroelectric plant located elsewhere). As a result, long-distance transmission would not be necessary to meet minimal local needs, unless a great shortage developed for industrial or urban requirements. When rerouting of power over long distances would be necessary, power loss problems would, of course, be encountered.

3. The structure of interconnections is so extensive that the system possesses sufficient flexibility to react to the needs that may be placed on it. In addition to having a largely automatic and well-dispersed hydroelectric system, PG&E has introduced many automatic switching installations to maintain continuing supplies of electricity to regions that have lost power or require more power (although even an automatic system would require some manual override control features). Where switching is done manually, the system depends on communications and in the immediate postattack period this might create confusion. Given a short recovery time, however, the system could attain a highly efficient, balanced state of operation. In addition, the PG&E system is interconnected with Southern California Edison[1] to the south as well as with power systems to the north. The Bureau of Reclamation also operates important hydroelectric plants in the area (most important of which is Shasta Dam). These give the system added flexibility.

1/ Moody's Public Utility Manual, 1958, Moody's Investor Service, New York, 1958, p. 998, shows Southern California Edison to have 25 hydroelectric plants with an aggregate effective operating capacity of 636,920 kw on December 31, 1957, which represented 24 percent of its total generating capacity. In addition, the system was interconnected with Hoover Dam.

4. PG&E has a large crew of line construction workers that could be called into service quickly to assist the normal maintenance crews in repairing the system and putting it back into operation. Some 7,500 workers, most of whom are located outside of major metropolitan areas, could be mobilized on short notice for repair work. Unlike electric utilities in other sections of the country, it is common for utilities in the West to have their own line construction crews. This large reserve of company-available technicians eases the emergency recovery problem.

Surface Water Supplies

In 1949 gravity flow provided irrigation water to 80 percent of the total acres irrigated by surface water in the 17 western states, whereas 12 percent of the surface water was provided by pumps only and 3 percent by a combination of pumps and gravity flow.[1] Much of the gravity flow water originates from irrigation dams and reservoirs, and some doubtless requires pumping at the source. However, such dams can usually supply their own power and few are considered to be targets in the postulated series of attacks. In addition, a considerable portion of the gravity flow is supplied by stream diversion rather than from reservoirs, and these sources are even less vulnerable to attack. Surface water supplies, in sum, are not likely to be seriously affected by nuclear attack in most areas.

Contamination of Water by Fallout

The effect of a nuclear attack on contamination of most ground water supplies would be negligible, and the contamination of surface water supplies would also be small for most fallout conditions. One estimate indicates that under extreme assumptions, less than 150 roentgens internal dose would be received by a man drinking from a surface reservoir in an area where the radiation intensity is 3,500 r/hr at H plus 1 hr (dose during 90 days from water averaging 20 feet in depth, 10 percent soluble fallout).[2] This level of internal dose is serious but probably not

[1] *1950 Census of Agriculture*, Vol. III, Bureau of the Census, Washington, D.C., p. 62.

[2] Hawkins, M. B., *Summary of Problems Relating to Local Fallout Contamination of Water Supplies*, University of California, Civil Defense Research Project, February 24, 1959, Tables III and X.

fatal, since it would be more localized than an equivalent amount of "whole body" radiation. Since livestock presumably could also tolerate ingestion of contaminated water from an area of 3,500 r/hr radiation intensity, livestock tolerances for fallout in surface water would be higher than the maximum external radiation tolerances (100 r/hr for pastured livestock and 1,000 r/hr for sheltered livestock) derived in Chapter III.

Contamination of crops from irrigation water delivered by means of ditches is not expected to be a major problem because contaminated particles would be largely insoluble. Most of the material would be absorbed by soil in ditches and fields, leaving little to be taken up by plants. Sprinkler irrigation with surface water would offer a greater contamination hazard because it would deposit particles directly on plant leaf and fruit surfaces.[1]/ However, sprinkler irrigation with ground water would not add contamination, and could in fact reduce the hazard by washing deposited fallout off the plants.

Vulnerability Summary

Inasmuch as more than half of all irrigation water is obtained by gravity flow from surface supplies in the West, the primary consideration of vulnerability is that of irrigation dams and reservoirs. With the possible exception of a few of the largest multipurpose dams such as Shasta and Grand Coulee, surface water sources are not expected to be major targets of nuclear attack. Their losses, and the loss of electrically pumped water, would be largely correlated with enemy objectives for destroying electric power facilities. Contamination of irrigation water supplies is not a generally serious potential problem. Therefore, vulnerability of irrigation water supplies can be associated with vulnerability of electric power and will not be separately considered in subsequent parts of this analysis.

1/ *Radioactive Fallout in Time of Emergency*, ARS 22-55, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, D.C., April 1960, p. 29.

PRODUCTION

NUTRIENT

DISTRIBUTION
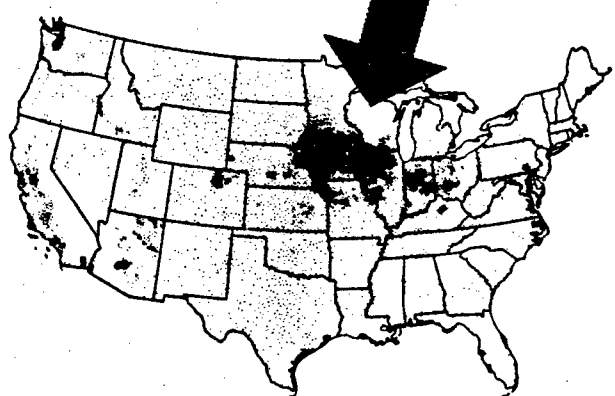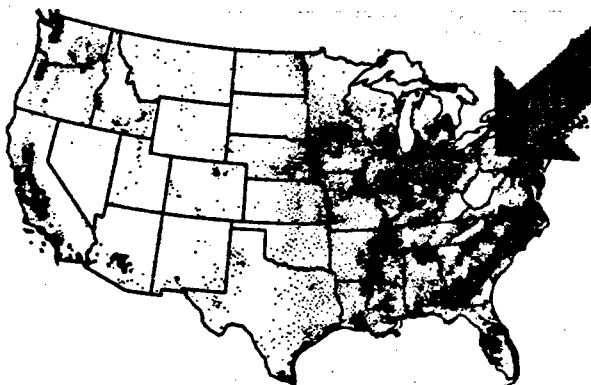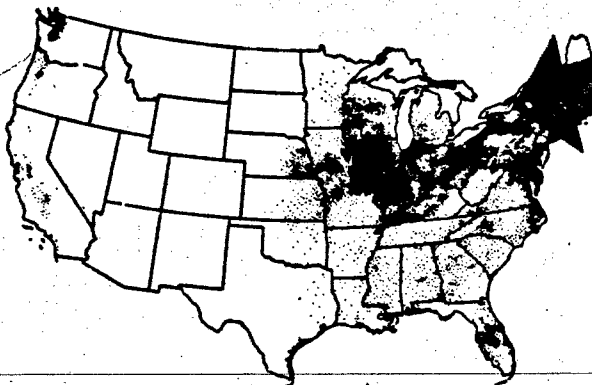
Chapter IX

SOIL NUTRIENTS

Section 1: General

In the past few years the acreage devoted to growing crops has remained static and the number of people employed on farms has decreased,[1] but the use of soil nutrients has grown apace. Figure 11 shows the consumption of phosphate, potash, and nitrogen fertilizers since 1940 with a projection to 1965; the title illustration (opposite) shows the major distribution and uses of these nutrients in manure and commercial fertilizers as well as secondary nutrients in liming materials.

Use of soil nutrients has increased because their prices have increased much less rapidly than have those of other agricultural inputs (particularly land) for which soil nutrients can be substituted.[2] In the past, decreases in nutrient prices relative to other farm inputs have been due largely to improvements in commercial fertilizer technology, and future changes in the price relationship can likewise be expected to be tied to the technology.[3]

The importance of soil nutrients is indicated by the Department of Agriculture's estimate,[4] based on 1954 practices, that average production from 1953 to 1955 of all crops and pasture would fall by 30 percent if no soil nutrients were applied. The full reduction would not occur until residual effects of past applications were exhausted after several years.

The importance of a soil nutrient in a postattack economy would depend greatly on the type of nutrient and the form in which it is applied.

1/ *Agricultural Statistics, 1959*, U.S. Department of Agriculture, Government Printing Office, Washington, D.C., pp. 438 and 451.

2/ Rultan, Vernon W., and Calvin R. Berry, "Role of Fertilizer in Changing the Agricultural Economy," *Agricultural Chemicals*, February 1960, pp. 35-36.

3/ Ibid.

4/ *The Economic Position of Fertilizer Use in the United States*, Agriculture Information Bulletin, No. 202, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, D.C., November 1958, p. 12.

FIG. II
CONSUMPTION TRENDS OF PRIMARY SOIL NUTRIENTS, 1940-1965
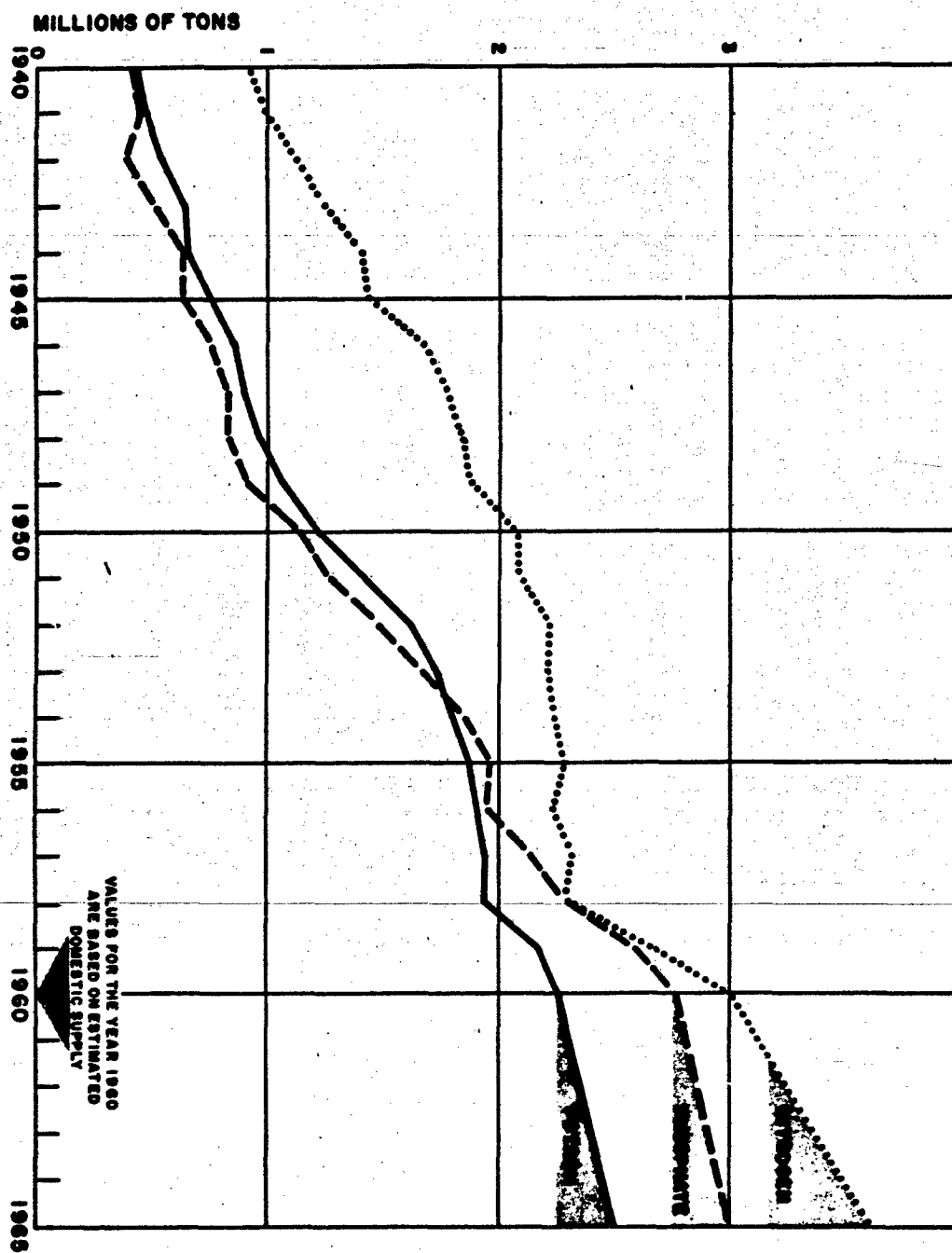
Therefore, the analysis in this chapter has been subdivided on the basis of type and form of nutrient. Manure, which contains a variety of nutrients, is discussed in Section 2 of this chapter; commercial fertilizer and its major components, nitrogen, phosphorus, potash (the three primary soil nutrients), and sulfur are intensively studied in Sections 3,4, and 5; liming materials containing calcium and magnesium (the secondary soil nutrients) are discussed in Section 6.

A second reason for considering soil nutrients in detail is that they present a broad cross section of the mining and chemical industries in this country (potash and sulfur mining; nitrogen, ammonia, and sulfuric acid synthesis; etc.), and illustrate some of the specialized postattack problems that might be faced by those industries. Commercial fertilizers, in particular, are of interest because they generally require complex production and distribution processes. Manures and limestone are not major items of trade. Manures are generally used directly without processing on the farm where they are produced, and limestone is mined in widely dispersed locations and distributed locally. The commercial fertilizer industry, on the other hand, has developed around less locally available sources of soil nutrients. For discussion purposes in this report the term "fertilizer" will be used to refer to commercial fertilizers only.

In addition to applications of manure, liming materials, and fertilizers, plant nutrients are added to the soil in a number of natural ways. Soil formation involving the weathering of minerals transforms unavailable plant nutrients to available forms. Rainfall annually supplies an average of seven pounds per acre of combined nitrogen in solution. Ground water movements carry along soluable nutrients, and this can be important for certain humid and irrigated soils. Finally, bacteria in the roots of legumes fix atmospheric nitrogen and provide residues which benefit succeeding crops. Conversely, soil nutrients are lost by erosion of the surface soil and by leaching.[1]

Since it is difficult to evaluate the effect of these natural factors, attention will be limited to crop removals and cultural replacements of soil nutrients. Table 16 shows the crop removal-cultural replacement balance of the three primary soil nutrients for 1947, with estimates for

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[1] The discussion of these factors is based on Mehring, A. L., and R. Q. Parks, "How Nutrients Are Removed from Soils," Agricultural Chemicals, October 1949, pp. 36-39.

Table 16

PRIMARY SOIL NUTRIENT REMOVAL-REPLACEMENT RELATIONSHIPS

Nutrient	Removed by Crops (thousands of tons)	Replaced by Nutrients Added to Soil (percent replaced of amount removed)		
		Fertilizer	Manure	Total
1947 Statistics[1]				
Nitrogen	3,446[2]	23%	37%	60%
Available Phosphoric Oxide	1,815	97	43	140
Potash	3,060	28	35	63
1959 Estimates[3]				
Nitrogen	4,300[2]	61	32	93
Available Phosphoric Oxide	2,200	117	39	156
Potash	3,800	57	31	88
1965 Projections[4]				
Nitrogen	4,800	75	30	105
Available Phosphoric Oxide	2,500	120	35	155
Potash	4,300	58	29	87

1/ Removal from A. L. Mehring and R. Q. Parks, op. cit., p. 36.
Replacement from A. L. Mehring, J. Richard Adams, and K. D. Jacob,
Statistics on Fertilizers and Liming Materials, Statistical Bulle-
tin No. 191, Agricultural Research Service, Washington, D.C., April
1957, pp. 17, 39, 46, 74.

2/ Non-legume removal only.

3/ Removal based on increase in the index of crop output by 24 percent
between 1947 and 1959. Agricultural Statistics, 1954, U.S. Dept.
of Agriculture, Washington, D.C., p. 462.
Replacement from Walter Scholl et al., "Consumption of Commercial
Fertilizers in the United States, "Agricultural Chemicals, Washing-
ton, D.C., February 1954, p. 32. Manure replacement, see Section 2,
this chapter.

4/ Removal based on estimated increase in the index of crop output by
16 percent between 1959 and 1965. Total replacement from Figure 11.
Manure replacement, see Section 2, this chapter.

1959 and projections to 1965. While manure was the most important source
of nutrient replacement in 1947, it no longer was in 1959 and it is ex-
pected to continue to decline in relative importance through 1965. Ni-
trogen fertilizer is the most rapidly growing nutrient product.

SHEEP

POULTRY

HORSES
& MULES

HOGS

CATTLE

PRODUCTION

MANURE
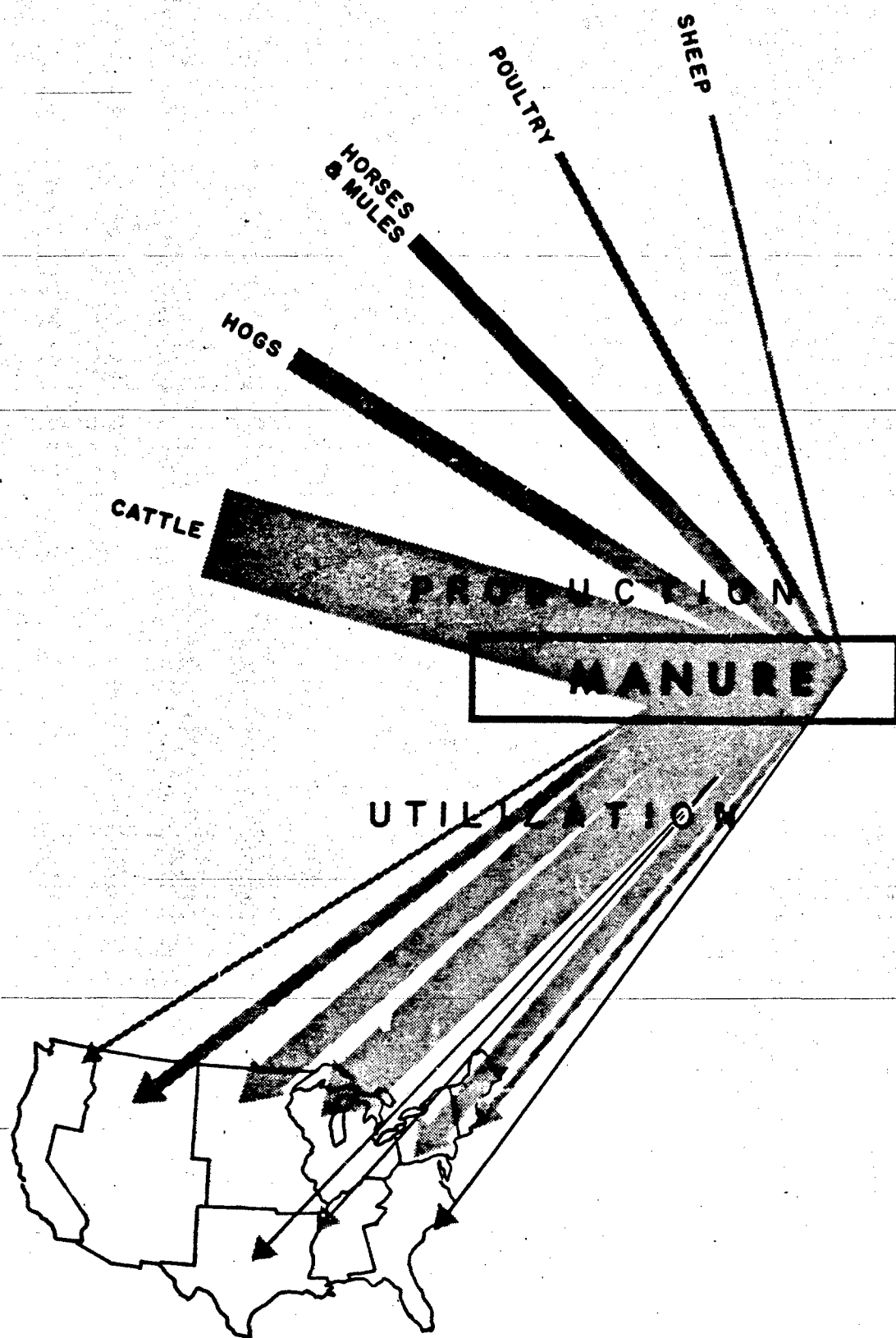
UTILIZATION

Chapter IX

SOIL NUTRIENTS

Section 2: Manure

Background

The latest comprehensive study of the production and utilization of manure was made in 1947.[1/] As shown in Table 16 in the preceding section, manure is still a significant source of soil nutrients, though its importance has decreased since 1947.

Only about 15 percent of the manure available on farms is used by farmers as a source of soil nutrients for crop production. This seeming waste of 85 percent is excrement dropped in pastures, particularly in the South and on the ranges of the West, where very little is collected.[2/] Manure utilization reportedly increased between 1927 and 1947 but the earlier data are believed to have been understated.[3/] Utilization practices may not, therefore, have changed greatly during the 1927-47 period. The assumption will be made that, despite development of modern collection and handling techniques, there have been no changes in percentage utilization since 1947.

Manure production in 1947 was distributed among farm animals as follows: cattle, 65 percent; hogs, 15 percent; horses and mules, 12 percent; poultry, 5 percent; sheep and goats, 3 percent.[2/]

1/ Mehring, A. L., J. Richard Adams, and K. D. Jacob, Statistics on Fertilizers and Liming Materials in the United States, Statistical Bulletin No. 191, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, D.C., April 1947, p. 39.

2/ Mehring, A. L., "Fertilizers," in Blanck, Fred C., Handbook of Food and Agriculture, Reinhold Publishing Corporation, New York, 1955, p. 90.

3/ Mehring, A. L., and R. Q. Parks, "Replacing Soil Nutrients with Fertilizer (Part II)," Agricultural Chemicals, November 1949, pp. 36-39.

Manure production in 1960 and 1965 can be estimated by assuming that (1) manure production is directly proportional to total livestock and poultry on farms,[1] (2) total livestock and poultry in 1960 is unchanged from 1959[1] and (3) the increase in manure production between 1947 and 1965 is 1.5 times the increase from 1947 to 1959. On this basis, the increase of 1960 over 1947 production will be approximately 9 percent and the 1965 increase over 1947 will be approximately 13 percent.

Vulnerability Summary

The following procedure was used to estimate losses to postattack manure production:

1. Losses of cattle and hogs, which in 1947 accounted for 80 percent of the manure production (and which today probably account for a larger percentage as fewer horses and mules are used on farms) are taken to be representative of all manure production losses. Production by cattle and hogs is distributed in proportion to the 1947 percentages given above, i.e., 65 percent and 15 percent, respectively.

2. Dairy cattle are considered separately from beef cattle since dairy animals can normally be housed in the immediately postattack period and given stored feed, while beef cattle will be more difficult to protect--either from direct radiation effects or from ingestion of radioactive material in feed. Numbers of dairy cattle were determined by multiplying the national totals of milk cows by 1.5 to take account of the number of heifers not otherwise included in the milk cow category. On this approximation, dairy cattle account for 31 percent of the total number of cattle.

3. Dairy cattle and hogs (both of which are assumed to be housed and fed from stored feeds) are considered to be lost if they are in areas with a fallout of over 1,000 r/hr at H plus 1.[2]

4. Beef cattle are considered to be lost if they are in a fallout area with over 100 r/hr at H plus 1 hr.[2]

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[1] Ibid.
[2] See Chapter III.

Table 17 shows surviving livestock, and Figure 12 shows resultant manure production estimated by the foregoing procedures. In general, neither of the early 1960's attacks seriously affect manure production, but losses from the late 1960's attacks would be extensive, even if utilization procedures were much improved. However, manure production losses are associated with heavy fallout areas where the land in any event would be difficult to farm.

Table 17

SURVIVING LIVESTOCK

	Beef Cattle	Dairy Cattle	All Cattle	Hogs
Early 1960's Attacks				
Military	80%	96%	85%	97%
Military-Population	60	79	66	86
Late 1960's Attacks				
Military	23	57	34	43
Military-Population	14	32	20	25

FIG. 12
MANURE PRODUCTION IN FIRST POSTATTACK YEAR

PERCENT OF PREATTACK

EARLY 1960s
MILITARY ATTACK
88

EARLY 1960s MIL.—
POP. ATTACK
71

LATE 1960s
MILITARY ATTACK
36

LATE 1960s MIL.—
POP. ATTACK
21

BY-PRODUCT
FROM COKE

IMPORTS

PRODUCTION

NITROGEN

MIXING

DISTRIBUTION

FARM USES

NON-FARM USES
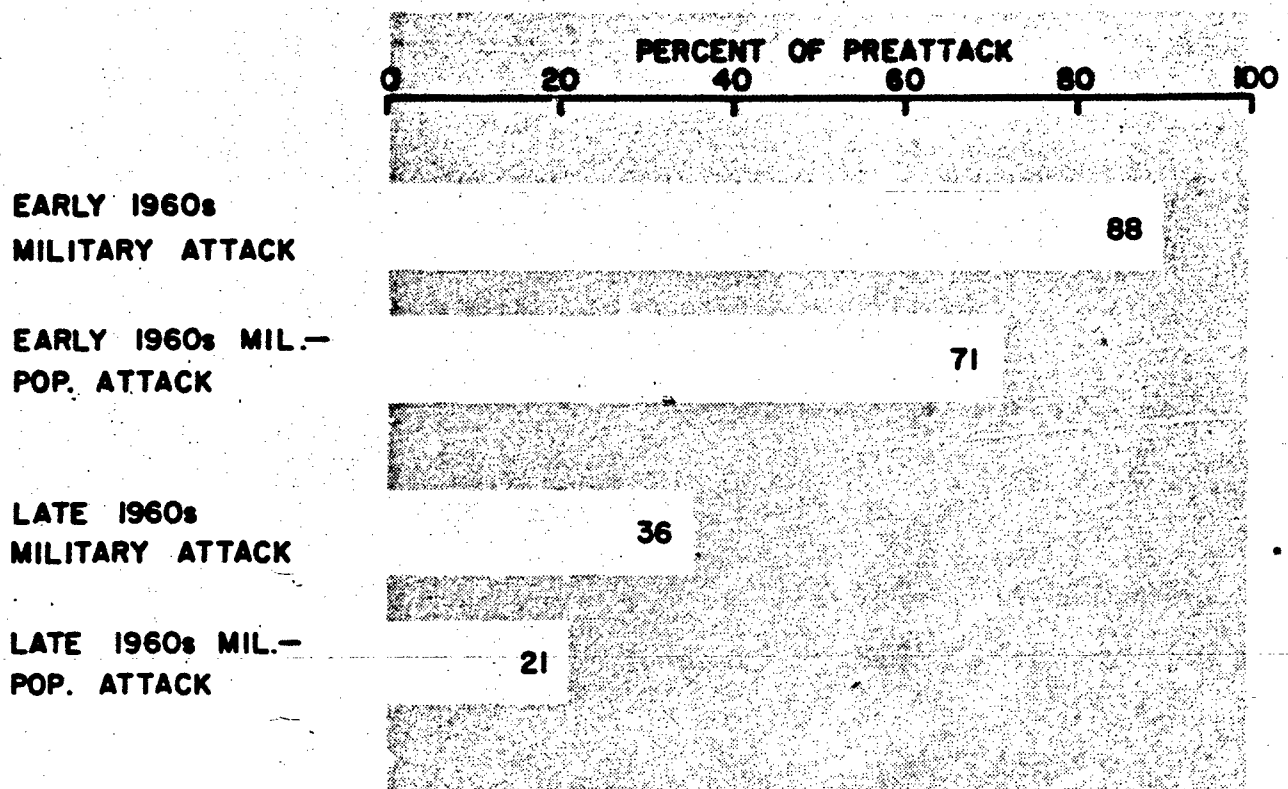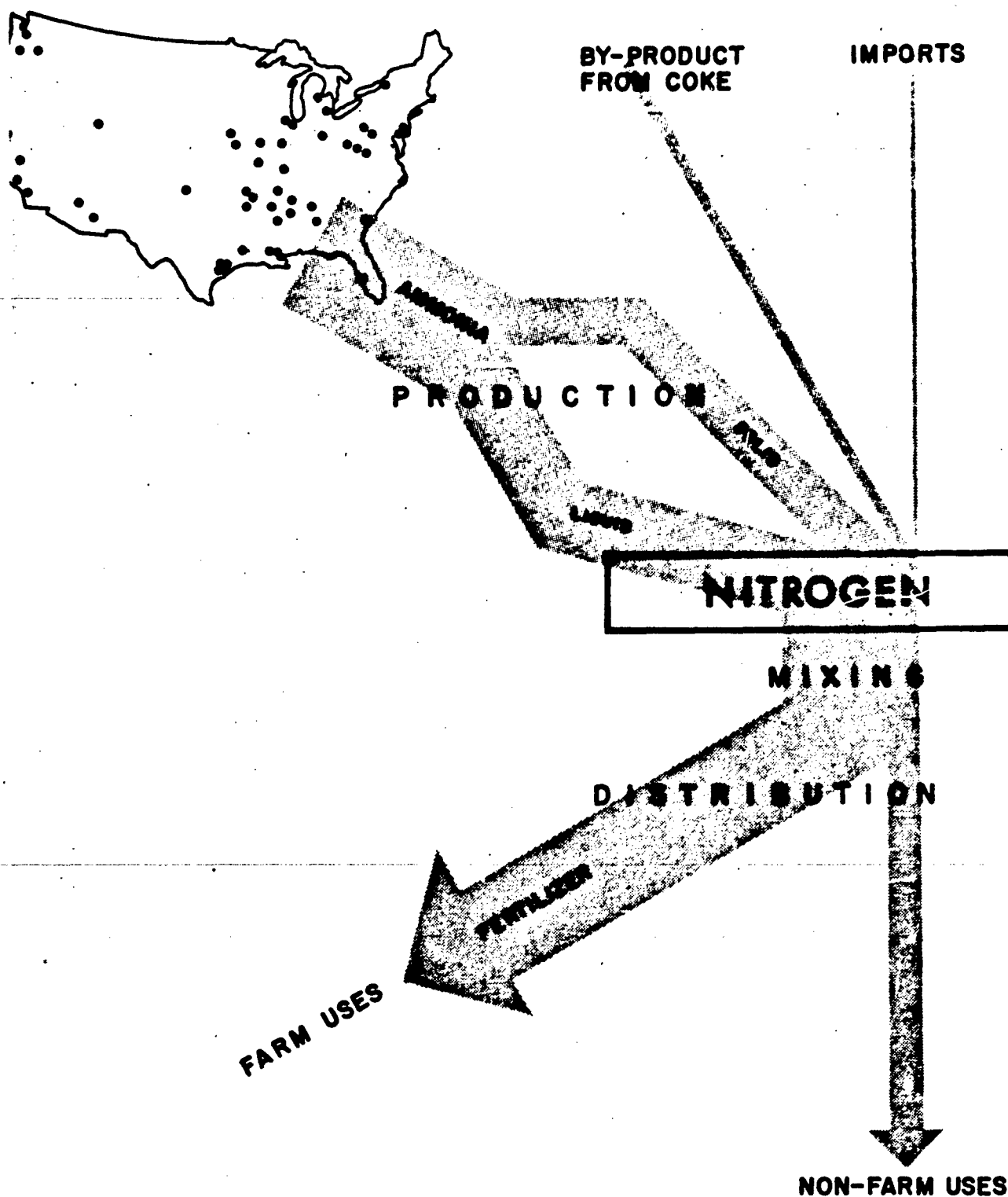
Chapter IX

SOIL NUTRIENTS

Section 3: Nitrogen

Background

At one time natural organic materials, Chilean sodium nitrate, and ammonium sulfate as a by-product from the operation of coke oven plants were the most important sources of fixed nitrogen; today synthetic ammonia is the dominant source. Synthetic production in 1960 was 4.8 million tons. Natural organic production of nitrogen was only 30 thousand tons in 1957, and by-product production was only 214 thousand tons.[1,2] Manufacturers of coke are considering discarding the nitrogen by-product rather than going to the expense of recovering it.[3]

Although imports of nitrogen materials have at times been high, net imports for the year ended June 30, 1960, were estimated at only 3 percent of domestic supply.[4] Exports are also small relative to total capacity, and both will be ignored in this analysis.

Nitrogen fertilizers are applied to the soil both as solids and liquids. The supplies of fertilizers in solid form from domestic sources for the year ended June 30, 1960, were estimated at 39 percent of the total and were distributed as follows: ammonium nitrate, ^39,000 tons; ammonium sulfate, 346,000 tons; urea, 131,000 tons; all other solids,

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1/ Williams, Moyle S., "Capacity, Production, and Use of Plant Food in the United States; 1952-58," Plant Food Review, Summer-Fall, 1958, p. 25.

2/ The nutrient content of nitrogen fertilizers is the weight of nitrogen present in the material; 100 tons of anhydrous ammonia contain 82 tons of nitrogen, whereas 100 tons of ammonium sulfate contain 21 tons of nitrogen.

3/ Oil, Paint, and Drug Reporter, June 23, 1958, p. 10.

4/ The Fertilizer Situation for 1959-1960, Commodity Stabilization Service, Washington, D.C., March 1960, p. 4.

238,000 tons. Liquid forms are increasingly popular, accounting in 1960 for 61 percent of the total, with ammonia (anhydrous and aqua) accounting for 925,000 tons and all other liquids for 895,000 tons.[1]

Anhydrous ammonia is the basic product of the synthetic nitrogen industry, and it is from this compound that the other nitrogen materials (ammonium nitrate, urea, synthetic ammonium sulfate) are derived. But to use this compound directly as fertilizer creates handling difficulties, because it must be stored and shipped in steel containers capable of withstanding pressures of more than 250 pounds per square inch and it requires special soil application equipment.[2]

Low pressure liquid nitrogen fertilizers, such as aqua ammonia, should be shipped and stored in containers able to withstand pressures of 25 pounds per square inch or more and are also best applied with special equipment. Non-pressure liquids, such as water solutions of urea or ammonium nitrate, can be applied with equipment similar to that for low pressure liquids, but they require the most processing.

Agriculture consumes 75 percent of the synthetic ammonia produced,[3] and industry (e.g., explosives manufacturing) uses 25 percent. Installed production capacity as of January 1, 1960, was 5.2 million tons of ammonia per year,[4] or 4.3 million tons of nitrogen. Domestic consumption of nitrogen fertilizers in 1960 is expected to be about 3.0 million tons of nitrogen.[5]

On the assumption that the agricultural demand for nitrogen in 1965 will be 75 percent of total nitrogen demand, projected total 1965 demand for nitrogen will be 4.8 million tons of nitrogen. (See Figure 11 for projected agricultural demand.)[6] This will require some increase in current capacity.

1/ The Fertilizer Situation for 1959-1960, op. cit.

2/ Fertilizers Applied in Liquid Form, ARS 22-35, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, D.C., November 1956, p. 7.

3/ Petroleum Week, September 19, 1958, p. 57.

4/ Chemical Economics Handbook, Vol. VII, Stanford Research Institute, March 1960, p. 703.32.

5/ See Figure 11.

6/ A requirement based on a continuation of the 10-percent per year growth in production over the past 10-15 years would total 7.6 million tons.

Process Description

All synthetic ammonia is produced by the high pressure combination of nitrogen and hydrogen.[1] Since nitrogen is found in abundance in the air (from which it is separated by several methods),[2] ammonia production differences depend primarily on the source of hydrogen. The breakdown of capacity in 1960 by hydrogen source was: petroleum, 9 percent; natural gas, 81 percent; chlorine cells, 6 percent; coke oven gas, 2 percent; unknown (probably natural gas), 2 percent.[3] Obviously, the natural gas process[2] is of primary interest. The material, energy, and manpower requirements for this process are given in Table 18.

The processes involved in converting synthetic ammonia to some of the more important solid compounds used in the end product may be summarized as follows:

1. Ammonium Nitrate

Ammonium nitrate is prepared by reacting ammonia with nitric acid. Since nitric acid is produced by the catalytic oxidation of ammonia, ammonia is the basic material for the entire process.

2. Ammonium Sulfate

Ammonium sulfate is produced by the reaction of ammonia with sulfuric acid. The process is uncomplicated. A description of the procedure for manufacturing sulfuric acid appears in Section 4, Phosphorus.

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[1] There are at least 13 processes used for this synthesis (e.g., Haber-Bosch, Claude, Casals), but all rely on elevated pressures. Ferguson, Towle, and Tarrice, High Temperature Heat Utilization in Industry, report by SRI for U.S. Atomic Energy Commission, April 1961, p. 124.

[2] Faith, W. L., et al., Industrial Chemicals, 2nd Ed., Wiley & Sons, New York, 1957.

[3] Stanford Research Institute, Chemical Economics Handbook, op. cit., pp. 703.33A-703.33L.

Table 18

MATERIAL, ENERGY, AND MANPOWER REQUIREMENTS FOR SYNTHESIZING AND LIQUEFYING ONE TON OF AMMONIA

Input	Requirement
Natural Gas (92% CH_4)	26,000 cu ft
Catalyst for Shift Reaction (Iron Oxide)	0.3 lb
Synthesis Catalyst (Iron Oxide)	0.5 lb
Caustic Soda (100%)	8 lb
Monoethanolamine	0.3 lb
Fuel Gas (for driving compressors)	22,000,000 Btu
Electricity	108 kwh
Treated Water	1,070 gal
Raw Water	4,500 gal
Operators per Shift	7

Source: B. S. Duff, "Ammonia—Cost of Manufacture from Five Different Raw Materials," Petroleum Processing, February 1955, p. 225.

3. Urea

Urea is synthesized by the reaction of ammonia with carbon dioxide. The reaction is carried out at rather high pressures, but no greater than those required for the ammonia synthesis.

Vulnerability Assessment

1. Vulnerability of Primary Plants--By-Product Nitrogen

The vulnerability of by-product nitrogen is tied to the survival of slot-type coke oven installations. The vulnerability of these is discussed briefly in Chapter X, Pesticides. The results developed there show that losses from either of the hypothetical military and population attacks would be extensive while little loss would be sustained by the coke ovens from military-oriented attacks.

2. Vulnerability of Primary Plants--Synthetic Ammonia

Physical plants, manpower, and electric power are the critical inputs in ammonia synthesis. This industry has grown rapidly from 18 plants in 1950 in the United States to 58 plants in 1960. The capacities of these 58 plants, either operating or under construction,[1] has been taken as the basis for all vulnerability estimates under the assumption that further growth in new locations by 1965 would not significantly change the expected average plant vulnerability.

The procedure outlined in Chapter II has been used to convert from H plus 1 hr radiation levels to estimates of surviving capacity. Table 19 shows the expected condition of the synthetic ammonia industry on a plant and associated manpower vulnerability basis for each of the four hypothetical attacks.

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[1] As listed in Stanford Research Institute, Chemical Economics Handbook, Vol. VII, Menlo Park, California, March 1960, p. 703.32.

Table 19

SYNTHETIC AMMONIA PLANT CAPACITY
IN FIRST POSTATTACK YEAR

Early 1960's Attacks

Military	97%
Military-Population	82

Late 1960's Attacks

Military	77
Military-Population	38

While some of the plants indicated as lost might be decontaminated and brought back into production, the supply of manpower with sufficient skills for ammonia plant operation would be limited.

Plants producing solid nitrogen materials would survive in roughly the same proportion as would ammonia plants, since, of the 39 synthetic ammonia plants having annual capacities of over 50,000 tons of ammonia at year-end 1957, 28 had facilities for producing solid nitrogen compounds at the same locations.[1]

3. Vulnerability of Electricity

The electricity requirement for ammonia production is large (108 kwh/ton). (For a comparison, the average home use of electricity was less than 8 kwh per day in 1955.)[2] Hence, in areas where the synthesis plants and associated manpower survive and other vital inputs are available, extensive losses to the local electricity supply could temporarily

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[1] Chemical and Engineering News, August 12, 1957, p. 26.

[2] Estimated Future Power Requirements of the United States by Regions, 1955-1980, Federal Power Commission, Washington, D.C., December 1956, p. 8.

constrain ammonia production. Power shortage was an important factor in the decline in Germany's nitrogen production in 1945.[1]

However, electric generation losses (based on stations damaged or experiencing H plus 1 radiation greater than 3,000 r/hr) would not be extensive in three of the four hypothetical attacks considered. Although losses in the electric distribution system could conceivably limit the electricity supply, in general, the distribution system is flexible enough to respond to most of the requirements that might be placed on it.[2] For the sample attacks considered, electric power is not likely to be a constraining factor on synthetic ammonia production, except after the late 1960's military and population attack.

4. Vulnerability of Natural Gas Supplies

According to Table 18, 26,000 cu ft of natural gas are required per ton of ammonia as a hydrogen source. (Other references estimate the requirement at as low as 10,000 cu ft.) If the fuel requirement to synthesize ammonia is also provided by natural gas, an additional 24,000 cu ft are required.[3] The quantities are significant; natural gas, particularly as a hydrogen source but also as a fuel, is unquestionably a critical input--and over the short run, it is an input for which there is no substitute.

Some natural gas originates in "dry gas" fields and is not processed through natural gasoline plants as is gas that originates in oil or "condensate-type" fields. However, the greatest part of the natural gas is processed through natural gasoline plants.[4] For this reason and because of the proximity of natural gas fields to gasoline plants, losses

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1/ Impact of Air Attack in World War II; Selected Data for Civil Defense Planning, Division II, Vol. I, Stanford Research Institute, June 1953.
2/ See Chapter VII, Electricity.
3/ The heat of combustion (net basis) of methane is 913 Btu/cu ft where the gas is dry and at 60°F and 30 in. of Hg. Kirk, Raymond E., and Donald F. Othimer, Encyclopedia of Chemical Technology, Vol. 7, The Interscience Encyclopedia, Inc., New York, 1951, p. 62.
4/ In 1956 a representative year, the net production of natural gas was 10,946 billion cu ft, with 8,590 billion cu ft being processed at natural gasoline plants. 1958 Gas Facts, American Gas Association, New York, 1958, pp. 26 and 33.

to natural gas production as a whole are estimated to be proportional to those natural gasoline plants that receive over 3,000 r/hr at H plus 1 hr. (See Table 20.)

Table 20

PRODUCTION CAPACITY OF NATURAL GASOLINE PLANTS
IN FIRST POSTATTACK YEAR

Early 1960's Attacks

Military	97%
Military-Population	94

Late 1960's Attacks

Military	46
Military-Population	39

Natural gasoline plant losses are seen to be no more than those of ammonia synthesis plants (except for the late 1960's military attack), and ammonia production demands only a small part of the natural gas supply. (The 3.0 million tons of ammonia produced from natural gas in 1957, figured at 50,000 cu ft of gas per ton of ammonia, amounted to only a little more than 1 percent of the net 1957 natural gas production of 11.6 trillion cu ft.) Therefore, large losses in natural gas capacity need not affect essential ammonia production unless the losses take the form of a total loss of gas from a sole-source area.

Natural gas pipelines are not particularly vulnerable to direct bomb damage and are not at all vulnerable to radiation (with the possible exception of the compression stations, which are located at 70- to 100-mile intervals along the pipelines). A study of losses to interstate petroleum product pipelines under the four hypothetical attacks concluded that losses to that system would not exceed 20 percent even in the worst attack.[1]

1/ The Effects of Nuclear Attacks on the Petroleum Industry, Stanford Research Institute, July 1960, Table 3.

In addition, although the gas pipelines are by no means as extensively interconnected or as flexible in operation as are electric power lines, interconnections do exist and could be used to provide gas to areas that would otherwise be without it. In sum, although natural gas losses for the heavier attacks would be serious, they would probably not constrain ammonia production except in a few special cases.

5. Vulnerability of Other Process Materials

The life of catalysts used in ammonia synthesis can vary over a range of between three months and seven years. Since companies have been unwilling to reveal details on catalyst replacement, it has not been possible to obtain any average performance value. Obviously, the need to replace catalysts may occur early in the postattack period in some plants, while for others it may not occur until well into the recovery period. Some catalyst stocks are likely to exist, so that the immediate postattack requirements for this input can probably be satisfied. The longer-run problem should not prove severe.

The caustic soda requirement of 8 pounds per ton of ammonia will total 23,000 tons for the 5.8 million tons of ammonia predicted for consumption in 1965.[1] However, this represents less than 1/2 of 1 percent of total caustic soda production[2] and could be easily provided under even the worst attacks. The monoethanolamine requirement is small, and other chemicals could be substituted for it should the need arise.

6. Transportation Requirements of Nitrogen Fertilizer

Nitrogen fertilizers are not marketed directly by the nitrogen fertilizer producers but instead are moved through the synthesis-mixing-distribution channels set up by the phosphate fertilizer manufacturers. Even the nitrogen fertilizers sold as straight (i.e., unblended) materials are marketed through mixing plant operations.[3] Since the mixing plants

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1/ This prediction of consumption is based on the 4.8 million tons of nitrogen production forecast for 1965. Basis for this latter forecast is developed in the "Background" discussion in this section.

2/ Industry, Inorganic Chemicals, M28A-19, Bureau of the Census and Business and Defense Services Administration, Washington, D.C., April 7, 1959, p. 5.

3/ Markham, Jesse W., The Fertilizer Industry, The Vanderbilt University Press, Nashville, Tennessee, 1958, pp. 26-29.

are located close to their respective agricultural markets, the major
question in evaluating the transportation requirement for nitrogen fer-
tilizers is the distribution of the synthesis plants.

The demand for nitrogen fertilizers is concentrated in the South
Atlantic, Midwest, and West Coast states.[1] Except for a concentration
of ammonia plants in the Gulf Coast region,[2] the plant locations cor-
respond closely to the agricultural markets, so that postattack movement
of nitrogen fertilizers should not pose a serious problem. If trans-
portation were critical, many plants could produce fertilizers of higher
nutrient content and thereby reduce the total weight of material by a
significant amount.

Vulnerability Summary

There are vulnerable features to the nitrogen fertilizer production
system. Foremost among them is the vulnerability of the ammonia plants
and their associated labor force. In addition, losses in electric power
generation could conceivably constrain production within the surviving
ammonia plants after the late 1960's military-population attack, when
only 42 percent of the electric generating capacity survives. Natural
gas and other non-local inputs do not appear to present a problem except
after the late 1960's military attack, when only 46 percent of natural
gas capacity survives. Transportation is not a problem. However, pro-
duction losses could possibly be less severe than losses to ammonia plant
capacity, because the industry has had excess capacity since 1952.[3]

Figure 13 shows the possible postattack production of ammonia plants,
on the assumption that production losses are equal to capacity losses.
For a more conservative estimate, the prediction of surviving ammonia
synthesis plant capacity shown in Table 19 has been reduced for the two
heavier attacks (late 1960's) because of the possible additional con-
straints in natural gas and electric power supplies.

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[1] Scholl, Walter, et al., "Consumption of Commercial Fertilizers and
Primary Plant Nutrients in the United States," Agricultural Chemicals,
February 1960, p. 32.

[2] Chemical Economics Handbook, Vol. VII, Stanford Research Institute,
March 1960, p. 703.32.

[3] Williams, Moyle S., "Capacity, Production, and Use of Plant Food in
The United States; 1952-58," Plant Food Review, Summer-Fall, 1958,
p. 25.

FIG. 13
SYNTHETIC AMMONIA PRODUCTION IN FIRST POSTATTACK YEAR

PERCENT OF PREATTACK

0   20   40   60   80   100

EARLY 1960s
MILITARY ATTACK   97

EARLY 1960s MIL.—
POP. ATTACK   82

LATE 1960s
MILITARY ATTACK   66

LATE 1960s MIL.—
POP. ATTACK   32

MINING

PROCESSING

PHOSPHATE

DISTRIBUTION

EXPORT

FARM USE

NONFARM
USES
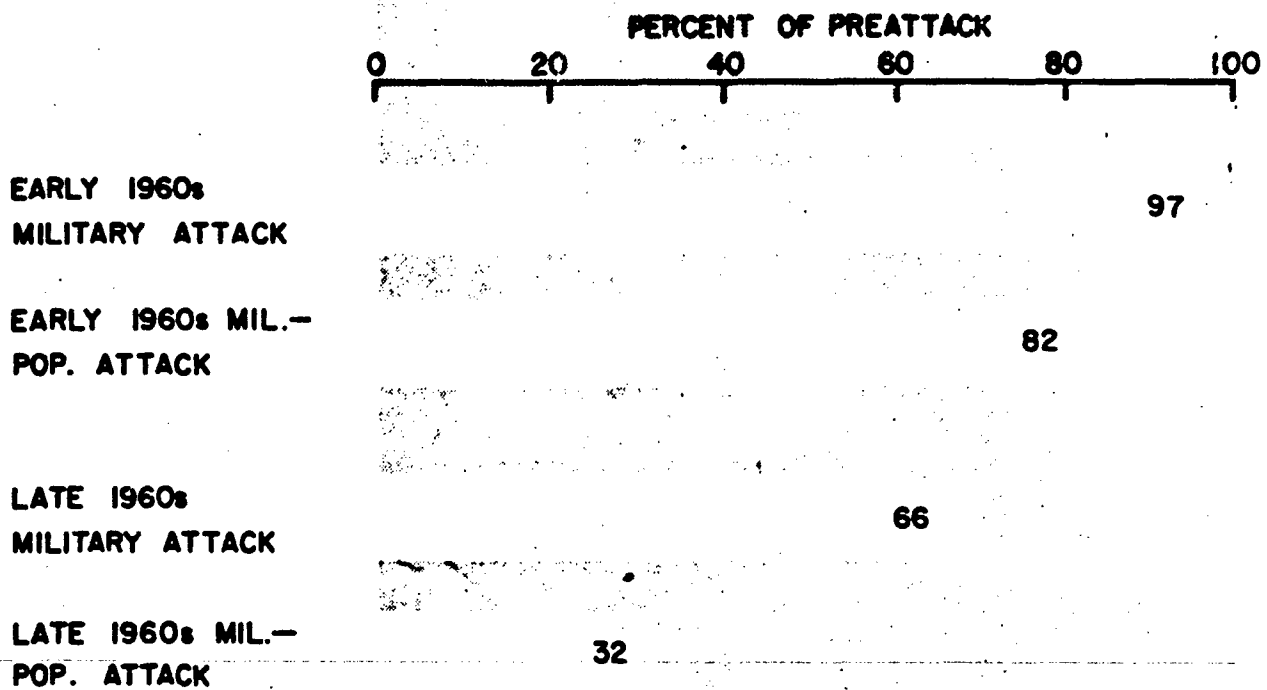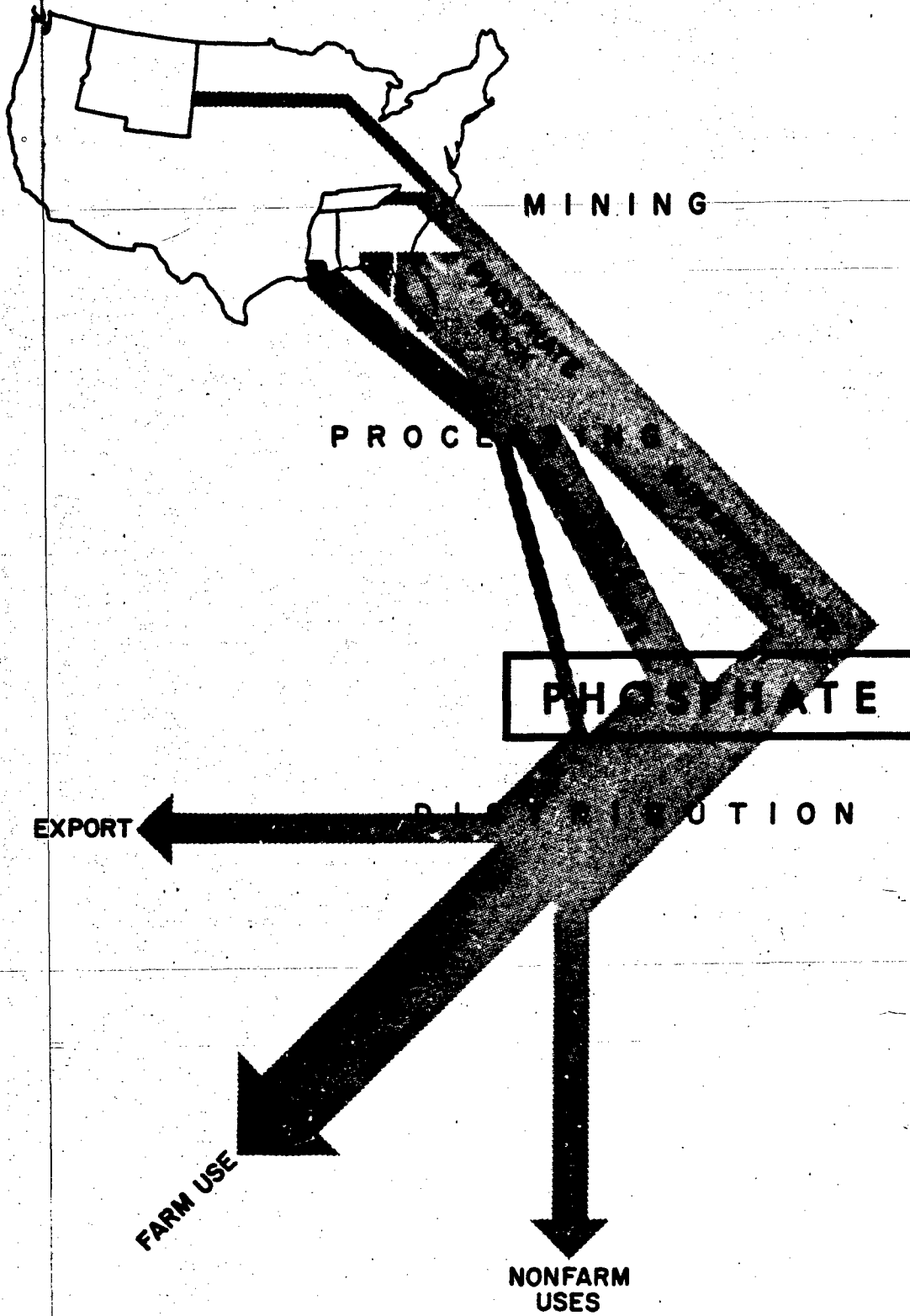
Chapter IX

SOIL NUTRIENTS

Section 4: Phosphorus

Background

In 1957 Florida produced 74 percent of U.S. phosphate rock; four western states (Idaho, Montana, Utah, and Wyoming) produced 14 percent; and Tennessee produced 12 percent.[1] However, not all of the phosphate rock produced was used for fertilizer; other ultimate uses are for matches, explosives, drugs, detergents, and textiles. Of the total production, 20 percent is converted into phosphoric acid for industry, 3 percent into other phosphorus chemicals, and 19 percent is exported.[1] Still, over half of total production is used for agriculture;[2] Table 21 details this latter portion. (Two conventions are followed here to express the quantities of phosphorus used in fertilizers. First, the phosphorus content is expressed as phosphoric acid anhydride (P_2O_5) equivalent; second, since some phosphorus is in a form that is not available to plants, the expression "available phosphoric oxide" is used.)[3]

In addition to phosphate rock, sulfur is necessary for the manufacture of most phosphorus fertilizers. In 1951, about 75 percent of the 5 million tons of sulfur (expressed as sulfur trioxide equivalent) applied to the soil was in the form of commercial fertilizers, and about 75 percent of the sulfur in commercial fertilizers was in the form of superphosphates.[4] However, sulfur is not needed in large quantities an a

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1/ Fertilizer Trends, TVA, Knoxville, Tennessee, September 1958, p. 13.

2/ Stovall, Robert H., "Lush Market," Barron's , November 21, 1960, p. 11.

3/ Siems, H. B., "Chemistry and Manufacture of Superphosphates and Phosphoric Acid," Fertilizer Technology and Resources in the United States, K. D. Jacob (Editor), Academic Press, Inc., New York, 1953, p. 7.

4/ Statistics on Fertilizers and Liming Materials in the United States, Statistical Bulletin No. 191, U.S. Dept. of Agriculture, Washington, D.C., April 1957, Tables 83 and 84.

Table 21

PHOSPHATE ROCK PRODUCTION FOR DOMESTIC FERTILIZER APPLICATION
BY SOURCE AND BY TYPE OF APPLICATION, 1957
(Thousands of Long Tons)

	Florida		Tennessee		Four Western States		United States	
	Amount	Percent of U.S. Total	Amount	Percent of U.S. Total	Amount	Percent of U.S. Total	Amount	Percent of U.S. Total
For Superphosphates	6,457	82%	162	3%	419	5%	7,038	90% [1]/
For Direct Application to the Soil	598	8	93	1	2	—	693	9
For Other Uses	7	—	107	1	—	—	114	1
Total	7,062	90%	362	5%	421	5%	7,845	100%

[1]/ Normal superphosphate accounts for 57 percent and triple superphosphate for 33 percent.

Source: TVA, op. cit., p. 13.

120

nutrient, since the chief source of soil sulfur is weathering of minerals.[1] For this reason, sulfur is considered in this chapter together with phosphorus.

Phosphate rock can be applied to the soil directly, thereby eliminating a large part of the need for agricultural sulfur in manufacturing phosphorus fertilizers, and requiring no processing other than grinding.[2] However, the available nutrient content of ground rock is comparatively low, only 5 to 10 percent of the total P_2O_5 being available to plants[3] as compared with 18 to 21 percent in normal superphosphate and 43 to 50 percent in triple superphosphate. Nonetheless, direct applications might be the most feasible method for a postattack situation in which normal operations could not be continued, in spite of the increased transportation required in delivering the unprocessed rock to the farm.

Process Description

The following process description is divided into four parts: mining phosphate rock; obtaining sulfur and converting it to sulfuric acid; manufacturing normal superphosphate; and manufacturing triple superphosphate.

1. Mining Phosphate Rock

Florida phosphate deposits are mined entirely by open-cut methods. The overburden of sand and clay is removed by electric draglines, and the matrix is then removed by dragline and dumped into a sump where it is pumped with water to the recovery plants. Here the phosphate is separated from the waste material and finally is dried.

Assuming that the power requirement can be satisfied, this process does not appear to have any vulnerable features other than its dependency on manpower familiar with the type of equipment involved. It might be noted that the very process used for removing the ore can also be used to decontaminate the field.

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[1] Blanck, Fred C., Handbook of Food and Agriculture, Reinhold Publishing Corporation, New York, 1955, p. 55.

[2] Jacob, Fertilizer Technology and Resources in the United States, op. cit., p. 158.

[3] Ibid.

Open-cut mining is also used by all companies in the Tennessee brown-rock phosphate fields. The matrix is transported to the recovery plant by rail or truck.

Since western phosphates are usually found in fissure veins between walls of limestone and clay or shale, they are mined chiefly by underground methods.[1] Selective mining is often practiced so that subsequent concentration of the ore is not necessary.

2. Sulfur Mining and Sulfuric Acid Manufacture

In 1957 domestic sulfur production by source was: Frasch-process, 80 percent; natural and industrial gases, 7 percent; pyrites, 6 percent; by-products from smelters, 6 percent; other by-product sulfur, 1 percent.[2] Although changes in domestic patterns may occur, Frasch-process sulfur will probably be the major domestic source in 1965. Its use has recently been expanded with new offshore wells which are replacing exhausted domes.[3]

The Frasch-process for recovering sulfur is an ingeniously simple one. A well is drilled into the sulfur-bearing deposit and three stringers of concentric pipe, perforated near the bottom, are lowered to the bottom of the hole. Superheated water is pumped into the well through one pipe to melt the sulfur. The molten sulfur is forced to the surface through the second annular space by compressed air forced down the innermost pipe.[4]

Sulfuric acid is made by two processes: the chamber process and the newer contact process.[5] In 1954 the contact process accounted for

1/ Faith, W. L., et al., Industrial Chemicals, 2nd ed., Wiley and Sons, New York, 1957, p. 598.
2/ "Sulfur and Pyrites," preprint from Minerals Yearbook, 1957, Bureau of Mines, Washington, D.C., p. 3.
3/ Newsweek, June 13, 1960, p. 79.
4/ Faith, Industrial Chemicals, op. cit., p. 737.
5/ Gribbins, W. F., "Conversion of Ammonia to Fertilizer Materials," Fertilizer Technology and Resources in the United States, K. D. Jacob (Editor), Academic Press, Inc., New York, 1953, pp. 73-75.

83 percent of production[1] but since the chamber process is still in wide use by fertilizer plants,[2] requirements for both are detailed in Table 22.

Table 22

REQUIREMENTS FOR MANUFACTURING ONE TON OF 100 PERCENT SULFURIC ACID

	By Contact Process	By Chamber Process
Sulfur	688 lb	677 lb
Water	4,000 gal.	2,500 gal.
Steam	200 lb	--
Electricity	5 kwh	15 kwh
Air	250,000 cu ft	275,000 cu ft
Nitrogen Oxides	--	5 lb

Source: Faith, op. cit., pp. 743 and 745.

3. Normal Superphosphate Manufacture

The procedure for making normal superphosphate is simple. It involves grinding the phosphate rock and mixing it with sulfuric acid, moving the soupy mixture into dens (i.e., large cylindrical or rectangular rooms) for a day to allow it to set up in solid form, and then to piles for 8 to 10 weeks to allow the reaction to go to completion.[3] The two inputs that are required in quantity in this process are phosphate rock and sulfuric acid. One thousand two hundred pounds of phosphate rock (assaying 30 percent P_2O_5) and 1,200 pounds of 62 percent sulfuric acid (the equivalent of 750 pounds of 100 percent acid or about 250 pounds of pure sulfur) are required per ton of normal superphosphate.

1/ Faith, Industrial Chemicals, op. cit., p. 744.
2/ "Plant Survey," Chemical Week, September 27, 1958, pp. 41-50.
3/ Faith, Industrial Chemicals, op. cit., p. 201.

4. Triple Superphosphate Manufacture

Triple superphosphate plants at present all use wet process phosphoric acid.[1] This acid is prepared by reacting phosphate rock with sulfuric acid under controlled conditions. The phosphoric acid is then reacted with phosphate rock by a process similar to that used for making normal superphosphate. However, the triple superphosphate plants generally handle continuous rather than batch processing.

Vulnerability Assessment

1. Vulnerability of Primary Plants--Normal Superphosphate

In 1951 there were 202 normal superphosphate plants in the United States, 171 of which (representing 87.2 percent of the 1950 U.S. capacity) were located east of the Mississippi.[2] There were only five normal superphosphate plants in the Mountain and Pacific regions, and these accounted for less than 2 percent of the 1950 capacity.[3] Normal superphosphate growth has been slow since 1951; the number of plants in 1956 was only 7 more and the productive capacity only 7 percent greater than in 1951.[4] Even so, they have been operating at low average rates; 1957 total production was only 43 percent of capacity.[5]

Because there are so many normal superphosphate plants, no attempt has been made to enumerate losses from any of the four attacks. However, since these plants are in general widely dispersed and remotely located, losses to them and to their associated labor forces should not be excessive. Losses should be less than for most chemical production but more than for farm facilities in rural areas. Surviving capacity, representing the approximate average of available postattack workers in agriculture and in the chemical industry, is estimated in Table 23.

1/ Slack, A. V., "Developments in Superphosphate Production," Farm Chemicals, April 1959, p. 61.

2/ "New Data on Fertilizer Phosphate," Chemical Engineering, August 1952, p. 143.

3/ Ibid.

4/ Mehring, A. L., "Fertilizers," in Blanck, Fred C., Handbook of Food and Agriculture, Reinhold Publishing Corporation, New York, 1955, p. 43.

5/ Williams, Moyle S., "Capacity, Production, and Use of Plant Food in the United States; 1952-58," Plant Food Review, Summer-Fall, 1958, p. 26.

Table 23

AVAILABILITY OF WORKERS IN AGRICULTURE AND IN THE
CHEMICAL INDUSTRY IN FIRST POSTATTACK YEAR

Early 1960's Attacks

Military	90%
Military-Population	70

Late 1960's Attacks

Military	80
Military-Population	40

2. Vulnerability of Primary Plants--Triple Superphosphate

Triple superphosphate presents another situation. It is a more
concentrated product; hence, transportation costs are less significant.
Also, its production process requires phosphoric acid, which is more
complicated to produce and is less obtainable from outside suppliers
than the sulfuric acid used in normal superphosphate manufacture, so
that only large integrated plants have proved economical.[1] In 1957,
there were 16 triple superphosphate plants producing 2,235,000 tons per
year.[2]

Almost 80 percent of the U.S. total capacity is concentrated in
Polk and Hillsborough counties in Florida. Hillsborough County could be
a prime attack target because it has both a major metropolitan city
(Tampa) and a major air base (MacDill--which has recently been scheduled
for deactivation). If this county remains a military target area, it,
as well as neighboring Polk County, would be expected under the assumed
easterly fallout drift to experience H plus 1 hr radiation levels of
over 3,000 r/hr for all of the four hypothetical attacks. Assuming the
available shelter condition (basement equivalent) to be the most likely

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1/ Slack, A. V.,"Developments in Superphosphate Production: Part 2,"
    Farm Chemicals, May 1959, p. 55.
2/ For a listing of individual plants, see Chemical Week, May 4, 1957,
    p. 68.

to prevail, loss of virtually the entire work force from fallout in-
capacitation in these counties can be expected.[1] In addition, four of
the eight plants outside Florida are in or adjacent to major metropolitan
areas and can be expected to be lost in the military-population series of
attacks. Estimates of available triple superphosphate capacity following
each of the four attacks (based on vulnerability analyses of individual
existing plants and their associated labor forces) are given in Table 24.

Inasmuch as triple superphosphate accounted for 39 percent of the
production of superphosphates in 1958 (and the expectation is that this
percentage will increase in the years ahead),[2] the loss of this capacity
would be a major blow to the phosphate fertilizer industry.

Table 24

PRODUCTION OF TRIPLE SUPERPHOSPHATE IN
FIRST POSTATTACK YEAR

Early 1960's Attacks

Military	20%
Military-Population	10

Late 1960's Attacks

Military	17
Military-Population	7

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[1] Even under the modified shelter or blast warning shelter conditions,
losses from the more severe attacks would be extensive.

[2] Slack, "Developments in Superphosphate Production," op. cit., p. 56.

3. **Vulnerability of Critical Non-Local Inputs--Phosphate
Rock (Florida)**

Three different types of Florida rock are mined; each appears in a
slightly different location. However, land pebble deposits accounted
for 99 percent of the total in 1958;[1] thus the vulnerability of Florida
rock is essentially that of the land pebble deposits.

The land pebble deposits are found in two Florida counties: Hills-
borough and Polk.[2] These are the same counties that in the study of
triple superphosphate plants were considered to experience high fallout.
Hence, Florida production of phosphate rock following all attacks is zero.

4. **Vulnerability of Critical Non-Local Inputs--Phosphate
Rock (Tennessee)**

The Tennessee deposits that are actively mined are all brown rock
phosphate, and these occur chiefly in Maury County, but also in William-
son and Giles counties. These areas are not expected to be seriously
affected by either of the early 1960's attacks nor by the late 1960's
military attack. The late 1960's military-population attack would cause
these areas to receive radiation of 100 r/hr to 1,000 r/hr at H plus 1 hr.
Reasonably complete availability of these areas can be expected under the
assumed condition of protection in available shelter.

5. **Vulnerability of Critical Non-Local Inputs--Phosphate Rock
(Western States)**

The western states deposits are located as follows: Caribou, Bingham,
and Clark counties in Idaho; Powell, Beaverhead, and Silver Bow counties
in Montana; Rich County in Utah; and Lincoln County in Wyoming. Under
the available shelter condition, continued production from all western
states deposits should be possible following either of the postulated
early 1960 attacks. Both late 1960's attacks, however, are indicated as
saturating the Idaho, Wyoming, and Utah phosphate rock-producing areas
with heavy radiation, so that the Montana mines would be the only western

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1/ Mineral Industry Surveys, Mineral Market Report, MMS No. 2925, U.S.
   Bureau of Mines, Washington, D.C., July 1959.

2/ Minerals Yearbook 1956, Vol. I, "Metal and Minerals," U.S. Bureau of
   Mines, Washington, D.C., p. 908.

states deposits for which a trained working force would be available after either of these attacks.[1]

Phosphate rock production in 1957 was distributed among the western states as follows: Idaho, 65 percent; Montana, 26 percent; Wyoming, 8 percent;[2] Utah, insignificant. Assuming these production patterns to continue through 1965, losses to western phosphate rock production due to fallout hazards in the postattack period can be expected to exceed 70 percent following either of the late 1960's attacks.

Table 25 summarizes the expected losses in phosphate rock production following each of the postulated attacks. Four assumptions were required to make the preattack rock production estimates: (1) the proportions of rock used for fertilizer and non-fertilizer purposes would be the same in the 1960's as in 1957; (2) the amount of rock required for fertilizer purposes would increase proportionately to the increase in consumption of phosphate fertilizer; (3) the relationships between mining areas would remain unchanged from 1957; (4) postattack production would equal surviving postattack capacity. The results of the analysis show that losses to phosphate rock production would be extensive from all attacks.

6. Vulnerability of Critical Non-Local Inputs--Sulfur and Sulfuric Acid

The location of raw sulfur production involves studying a changing situation.

The United States has long been a net exporter of sulfur, but whether it will continue to be so is not clear. Mexico has recently become a major exporter of sulfur to the United States, and Canada can be expected to join by 1965.[3] The locational vulnerability of the Canadian and Mexican sources is negligible, and most of the sulfur producing areas along

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1/ A possibility that is recognized but that will not be given further consideration is that the mines in the areas of the western states phosphate deposits could afford the inhabitants excellent shelter and permit much higher survival ratios if they were provisioned with emergency rations and other necessities.

2/ Preprint from Minerals Yearbook 1957, U.S. Bureau of Mines, Government Printing Office, Washington, D.C., 1958, p. 6.

3/ Haynes, William, "Sulfur Production Patterns in North American and in the World," Chemical Week, May 16, 1959, pp. 108 and 110.

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Table 25

MINE PRODUCTION OF PHOSPHATE ROCK BEFORE AND AFTER ATTACK
(Thousands of Long Tons)

	Florida	Tennessee	Four Western States	Total United States Amount	Percent of Preattack Production	Percent of Preattack Fertilizer Use
Early 1960's Attacks						
Preattack Total Production	12,700	2,000	2,300	17,000	100%	180%
Preattack Fertilizer Requirement	8,500	400	500	9,400	55	100
Post Military Attack Production	0	2,000	2,300	4,300	25	45
Post Military-Population Attack Production	0	2,000	2,300	4,300	25	45
Late 1960's Attacks						
Preattack Total Production	13,800	2,100	2,500	18,400	100	180
Preattack Fertilizer Requirement	9,200	500	500	10,200	55	100
Post Military Attack Production	0	2,100	700	2,800	15	25
Post Military-Population Attack Production	0	2,100	700	2,800	15	25

the Gulf Coast in the United States are only slightly or not at all affected by the four hypothetical attacks. However, if the Gulf Coast production of Frasch-process sulfur were lost (by damage from an attack on oil facilities in Texas and Louisiana, for example) and the wells permitted to freeze, bringing this area back into production would involve drilling new wells.

Continued production of non-Frasch domestic sources of sulfur varies with the source. Recovery of sulfur from natural gas is largely done near the gas fields, and postattack production here may well be limited. Therefore, pyrites is a possible emergency source of sulfur, although its processing would pose difficulties. In order of importance to 1957 production, the sources of pyrites were: Polk County, Tennessee; Carroll County, Virginia; Shasta County, California; Dolores and Lake counties, Colorado; and slight amounts from Montana, Arizona, Pennsylvania, and Vermont. In general, these ores are remotely located and widely dispersed, and therefore some postattack production should be possible. By-product sulfuric acid from copper, lead, and zinc smelters would depend on continued smelter production, and the likelihood of this in the postattack period is problematical.

In general, the prospects for an adequate postattack sulfur supply are good. The Gulf Coast areas would probably survive, as well as certain other domestic sources. However, even if they were lost, imports from Canada and Mexico could be expected to satisfy the more essential requirements.

In addition, sulfuric acid manufacturing facilities are not particularly vulnerable. In 1956 about 100 of the normal superphosphate plants had sulfuric acid facilities at the same locations.[1] Moreover, in 1950, when 91 of 202 plants had companion sulfuric acid facilities,[2] these facilities supplied 66 percent of the sulfuric acid used in normal superphosphate production.

The normal superphosphate plants and companion sulfuric acid facilities are numerous and well-dispersed, offering relatively poor targets to the postulated attacks. Moreover, the fraction of the industry that depends on outside sources for acid derives it from local sources, because sulfuric acid has a low bulk value, and shipping costs are disproportionately high for long-distance shipments.[3]

1/ Sauchelli, Vincent, "Sulfur-Sulfuric Acid in the American Fertilizer Industry," Agricultural Chemicals, February 1956, p. 125.

2/ Chemical Engineering, August 1952, p. 143.

3/ Faith, Industrial Chemicals, op. cit., p. 780.

7. Transportation Requirements of Phosphate Fertilizer

Normal superphosphate plants are located near their markets, which often makes long distance shipments of phosphate rock and sulfur necessary. As seen from the process description, 1,200 pounds of phosphate rock and 250 pounds of sulfur are required per ton of normal superphosphate.

Over 90 percent of the phosphate fertilizer consumed in the year ending June 30, 1959, was in regions east of the Rocky Mountains.[1] On the assumption that this will still be so in the late 1960's, the post-attack transportation problem will be one of supplying plants located in this part of the country with phosphate rock and sulfur. As indicated in Table 25, the Postattack phosphate rock production is limited to Tennessee and the western states.

The Tennessee deposits are located almost at the center of the phosphate fertilizer market, so that transportation from this source to the fertilizer plants usually would not involve a shipment of over 750 miles, with most plants being well within a railway distance of 500 miles. Average shipping distance could therefore be taken to be 350 miles for rock mined in Tennessee.[2] The western states have a different shipping problem: Even assuming that the westernmost plants are the ones served by these deposits, a shipment of 1,500 miles or more is required in order to reach any but the few western phosphate fertilizer plants local to the deposits.[3]

On the basis of 350 and 1,500 miles as the average shipping distances from the Tennessee and western states deposits, respectively, and on the assumption that fertilizer manufacturers can be provided with 85 percent of the total postattack output of phosphate rock (their

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[1] Scholl, Walter, et al., "Consumption of Commercial Fertilizers in the United States," Agricultural Chemicals, Washington, D.C., February 1954, p. 32.

[2] The assumption of a uniformly distributed phosphate rock requirement over the radius of 500 miles was used in developing the 350-miles estimate.

[3] It has been suggested that some of the technical advances in producing concentrated phosphate fertilizers will encourage production of greater amounts of phosphate fertilizers near the western deposits as it will be feasible to ship these concentrated forms for long distances. Baum, E. L., and S. L. Clement, "The Changing Structure of the Fertilizer Industry in the United States," Journal of Farm Economics, Proceedings, 1958, pp. 1191-1192.

preattack share in 1957 was 55 percent when 20 percent was exported,[1]
the annual postattack material transfer is estimated, as shown on Table 26.

Table 26

POSTATTACK TRANSPORTATION REQUIREMENTS OF PHOSPHATE FERTILIZERS

Type and Source of Phosphate Fertilizer	Amount (thousands of short tons)	Miles of Shipment Required	Total Ton-Miles of Shipment Transfer Required (millions)
Early 1960's Attacks			
Phosphate Rock (Tenn.)	1,900	350	650
Phosphate Rock (W. Sts.)	2,100	1,500	3,150
Sulfur (Gulf Coast)	850	1,000	850
			4,650
Late 1960's Attacks			
Phosphate Rock (Tenn.)	2,000	350	700
Phosphate Rock (W. Sts.)	650	1,500	1,000
Sulfur (Gulf Coast)	550	1,000	550
			2,250

Assuming that the Gulf Coast sulfur operations survive and that
these are the primary sources of postattack sulfur for phosphate ferti-
lizer manufacture, the average shipping distance for sulfur would be
about 1,000 miles. Demand for sulfur, however, will be limited by the
available phosphate rock so that only 850 thousand tons would be needed
after the early 1960's attacks and 550 thousand tons after either of the
late 1960's attacks.

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[1] *73rd Annual Report*, ICC, Washington, D.C., 1959, p. 176.

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Table 26 shows the total postattack transportation requirement of normal superphosphate for phosphate rock and sulfur following each attack. The total for the early 1950's represents less than 0.9 percent of the rail freight transportation performed by line-haul railroads; for the late 1960's, it is about 0.4 percent.[1]

Vulnerability Summary

In sum, the process for making phosphate fertilizers is uncomplicated; hence, the vulnerable features of the production system are the plant and raw material locations and their associated labor forces. Triple superphosphate plants would sustain high losses in all attacks. However, normal superphosphate plants are much less vulnerable and could expand their production greatly within present excess capacity to help satisfy postattack needs. (The normal superphosphate share of the market is expected to be about 50 percent in the early 1960's and 40 percent in the late 1960's.) Or, if adequate transportation were available, applications of raw phosphate rock might be greatly increased.

The postattack transportation requirement (without added quantities of raw rock) has been shown in Table 26 to be less than 1 percent of the total normal railroad freight traffic in the United States. This is a sizable demand, which might be deferred by higher railroad priorities, but it does not appear to be one that would be physically impossible for the rail system to meet.[2]

Of the essential raw materials, sulfur should be available in adequate amounts, but only 25 percent of phosphate rock production would survive the early 1960's attacks and 15 percent would survive the late 1960's attacks (see Table 25). This vital input would be the constraining factor in postattack phosphate fertilizer production. If necessary, it might be possible to re-enter the Florida phosphate rock fields following either of the military attacks. Of course, sufficient time would have to be allowed for radiation decay and decontamination steps but these could be done within perhaps six months if prior plans had been made and urgency were assigned to the job. However, such actions cannot be counted on under present preparedness conditions and will not be considered in

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1/ TVA, Fertilizer Trends, op. cit., p. 13.
2/ Dixon, Harvey L., Dan G. Haney, and Paul S. Jones, A System Analysis of the Effects of Nuclear Attack on Railroad Transportation in the Continental United States, Stanford Research Institute, April 1960.

the present study. Allocation of remaining production to fertilizer uses could almost double the surviving percentage, but because of competing demands for phosphate, this also cannot be counted on.

The prospective denial of phosphate rock mining areas is thus estimated to constrain over-all phosphate fertilizer availability in the first postattack year to the values shown in Figure 14.

FIG. 14
PHOSPHATE PRODUCTION IN FIRST POSTATTACK YEAR

PERCENT OF PREATTACK

EARLY 1960s
MILITARY ATTACK — 25

EARLY 1960s MIL.—
POP. ATTACK — 25

LATE 1960s
MILITARY ATTACK — 15

LATE 1960s MIL.—
POP. ATTACK — 15

(SASKATCHEWAN)

(UTAH)

(NEW
MEXICO)

M

R E   G

P O   H

D I S T   T I O N

WEST

EAST

NONFARM
USES
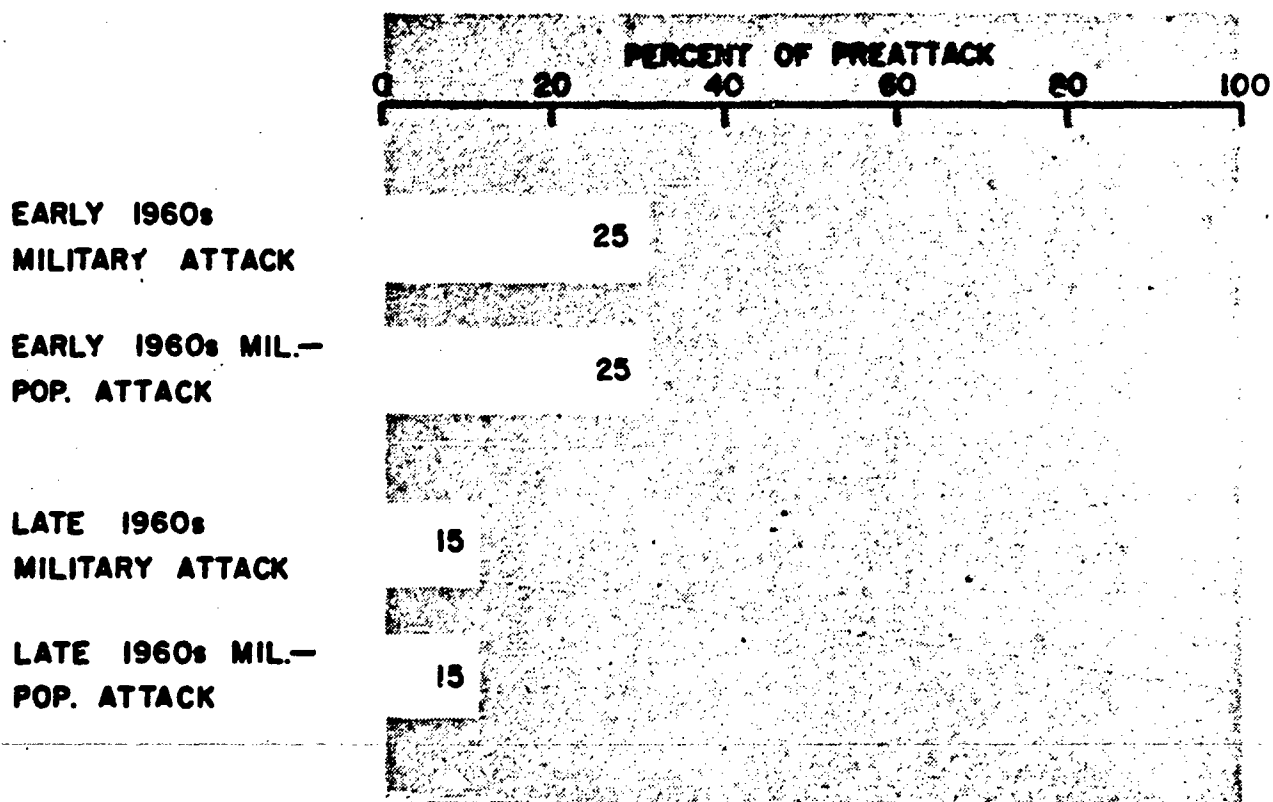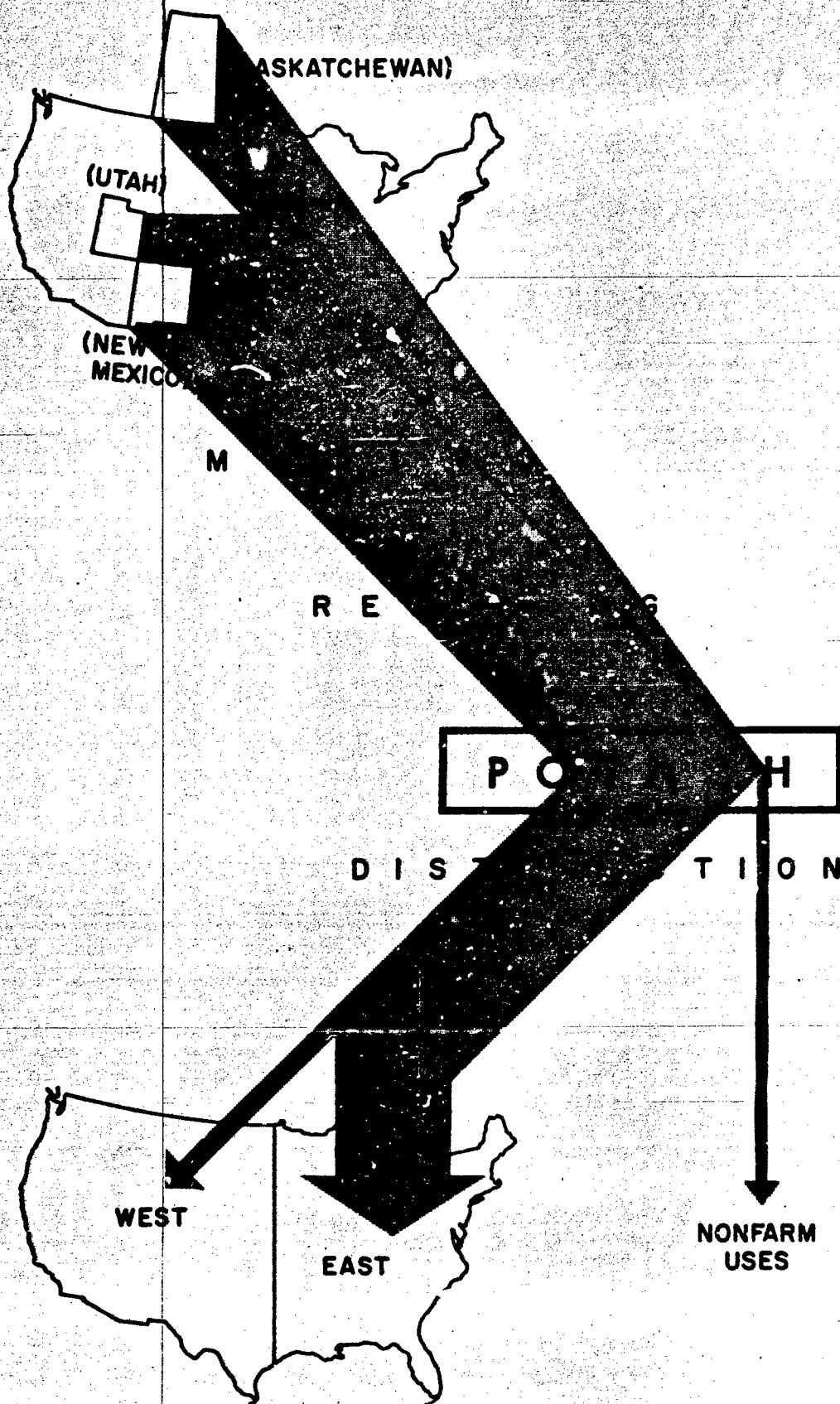
Chapter IX

SOIL NUTRIENTS

Section 5: Potash

Background

Usually potassium is applied to the soil as potassium chloride (KCl) or as potassium sulfate (K_2SO_4). In order to get a standard measure of the amount of nutrient contained in such potash products, each compound is expressed in terms of its equivalent weight of potassium oxide (K_2O). Until the late 1920's the major source of domestic potash was from salt brine at Searles Lake, California. At that time soluble potash salts were discovered in the Permian Basin of New Mexico (particularly near Carlsbad). By 1957 these New Mexico deposits supplied 92 percent of the potash output, a figure representative of their current production.[1] Two large new potash deposits have recently been discovered in Saskatchewan, Canada, and a new facility is being developed near Moab, Utah.[2] However, production difficulties have been encountered in the Canadian potash facilities; and no significant production is expected from either mine before 1961 or 1962. Since the future of all these developments is uncertain, the conservative assumption will be made that no significant production from the new facilities can be expected before 1965.

In 1958, 94 percent of total potash output was consumed agriculturally;[3] 90 percent of this was used as fertilizer mixes;[4] and 94 percent of the fertilizer mixes were composed of potash muriate (potassium chloride).[5]

1/ "Potash, Special Report," Oil, Paint, and Drug Reporter, October 27, 1958, p. 3.

2/ Stovall, Robert H., "Land Market," Barron's, November 21, 1960, p. 11.

3/ "Potash, Special Report," op. cit., p. 42.

4/ Ibid.

5/ The Fertilizer Situation for 1959-1960, Commodity Stabilization Service, U.S. Dept. of Agriculture, March 1960, p. 8.

Manure salts, which are no more than high-grade crushed ore,[1] currently constitute an insignificant fraction of the total potash output, although as recently as 1948 they provided as much as 7 percent[2] and could again should postattack conditions require it. Manure salts contain about 25 percent potassium oxide equivalent compared with 48 to 62 percent for muriates. The transportation requirement per ton of nutrient is therefore much greater for manure salts.

Domestic potash production capacity in 1960 was 2.5 million tons,[3] and over 2 million tons were consumed as fertilizers.[4] Consumption in 1965 is projected to 2.5 million tons (see Figure 11). Considerable expansion in domestic and/or foreign sources is expected to meet this expected demand.

In addition to being an important plant nutrient, potash possesses another characteristic that could make its application to the soil desirable in the postattack period: potassium has a depressant effect on plant absorption of Cesium 137 similar to the effect that calcium has on Strontium 90.[5]

Process Description

1. Mining Operations[6]

Underground potash mine equipment (including locomotives, shuttle cars, auger drills, loading equipment, fans, and crushers) is electrically driven. Normal equipment repairs are performed at shops carved out of

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1/ Harley, G. T., "Potassium Materials," Fertilizer Technology and Resources in the United States, K. D. Jacob, (Editor), Academic Press, Inc., New York, 1953, p. 295.

2/ Mehring, A. L., et al., Statistics on Fertilizers and Liming Materials in the United States, Statistical Bulletin No. 101, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, D.C., April 1957, p. 72.

3/ Tenth Annual Report of the Activities of the Joint Committee on Defense Production, Activities of U.S. Dept. of Agriculture, GPO, 1961, Exhibit 4, p. 163.

4/ Walter Scholl, et al., "Consumption of Commercial Fertilizers and Primary Plant Nutrients in the United States," Agricultural Chemicals, February 1960, p. 32.

5/ Fowler, Eric B., "How Plant Foods Protect Plants," Plant Food Review, Summer 1959, p. 28.

6/ The description of the mining operations is based on Harley, "Potassium Materials," op. cit.

the ore and located at the working level. Primary power is converted to the secondary power system at portable underground substations.

Ore blasting requires an average of three quarters of a pound of powder per ton of ore. In 1957 crude salts mined at Carlsbad averaged about 18 percent K_2O,[1] so that 1.9 million tons of potash fertilizer required 4,000 tons of powder. Ore is crushed at the shaft before being hoisted to the surface.

2. Ore Beneficiation[2]

Refining is usually done by a flotation process, although one of the producers uses a fractional crystallation procedure. Flotation requires that the ore be crushed to fine granules and combined with a flotation reagent to separate the sodium chloride from the potassium chloride.[3] The product is standard 97 percent muriate of potash (i.e., 97 percent KCl which is equivalent to 60 percent K_2O). Fractional distillation depends upon the difference in temperature solubility of potassium chloride and sodium chloride. Both processes are uncomplicated.

Vulnerability Assessment

1. Vulnerability of Primary Plants

Since ore processing is done at the mine or within a few miles of the mine, the locational vulnerability of mining and processing can be considered together.

Although the New Mexico potash deposits should be relatively unaffected by attacks in the early 1960's, this area probably would be blanketed with fallout from attacks in the later period. Under the assumptions of the late 1960's attacks, 10,000 r/hr at H plus 1 hr might be expected in the New Mexico locations, making postattack production impossible. The expected postattack survival of U.S. potash capacity for the four

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1/ Oil, Paint, and Drug Reporter, op. cit., p. 38.

2/ The process description is from Faith, op. cit., pp. 629-631.

3/ A typical flotation reagent is 0.2 lb of tallow amine and 0.22 to 0.24 lb of polyalkyl glycol per ton of processed ore. Faith, W. L., Industrial Chemicals, 2nd ed., Wiley and Sons, New York, 1957, p. 629.

hypothetical attacks would be: 100 percent after the two early 1960's attacks; and 0 percent after the two late 1960's attacks. However, there might be a small amount of postattack potash available from lake brine following the late 1960's attacks. Furthermore, the new Utah operations might develop substantial supplies (although the Utah operations might also be covered by fallout). The late 1960's estimate of zero postattack capacity is, therefore, a pessimistic one.

2. Vulnerability of Critical Non-local Inputs--Mining Inputs

The critical inputs (other than manpower) are electric power, blasting powder, and repair parts. Since the whole region is unaffected by the early 1960's series of attacks, electric power should be available. The blasting powder requirement is not great and should therefore not prove to be a problem. Equipment could probably be cannibalized as a temporary expedient if necessary. For the late 1960's attacks, the question of non-local inputs is overridden by the problem of widespread fallout in the area.

3. Vulnerability of Critical Non-local Inputs--Ore Beneficiation Inputs

There are no potentially vulnerable materials other than the reagents used in the flotation process. The fractional crystallation process does not require any particular reagents and is thereby even less vulnerable.

4. Transportation Requirements of Potash Fertilizer

Virtually all potash used by agriculture in 1959 was consumed in regions east of the Rocky Mountains;[1] consequently much rail transportation is needed to move potash from the New Mexico producers to the agricultural users.

The net supply of potash in the year ended June 30, 1960, is expected to be 2.25 million tons.[2] Since the material shipped is primarily

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[1] Scholl, "Consumption of Commercial Fertilizers and Primary Plant Nutrients," op. cit., p. 32.

[2] Commodity Stabilization Service, The Fertilizer Situation for 1959-1960, op. cit., p. 8.

standard 97 percent muriate of potash, shipment of one ton of potash requires the movement of 1.7 tons of processed material. With Louisville as the approximate center of the potash market, the average railroad haul from the mines is about 1,500 miles. Hence, shipment of 5.7 billion ton-miles is involved in getting the 1960 production to market. This represents 1 percent of the 1958 freight transportation performed by line-haul railroads.[1]

Vulnerability Summary

Although the mining and ore beneficiation processes do not appear to have any critical non-local inputs, the location of the deposits and refining plants is highly vulnerable to fallout from the late 1960's series of attacks. Total capacity is assumed to be lost after these attacks. The early 1960's series of attacks, however, leaves potash production capacity virtually intact.

The transportation requirement of potash in 1960 is estimated at 5.7 billion ton-miles, a significant requirement in itself and one that could strain postattack transportation somewhat. As a low value freight item, potash might be assigned low priority for transportation.

Figure 15 indicates estimated first-year postattack potash availability. Although no production is indicated after the late 1960's attacks, some amount might be available from lake brine and the new Saskatchewan deposits if transportation requirements could be met.

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[1] 73rd Annual Report, Interstate Commerce Commission, Washington, D.C., 1959, p. 176.

FIG. 15
POTASH PRODUCTION IN FIRST POSTATTACK YEAR

PERCENT OF PREATTACK

| | 0 | 20 | 40 | 60 | 80 | 100 |

EARLY 1960s
MILITARY ATTACK
100

EARLY 1960s MIL.—
POP. ATTACK
100

LATE 1960s
MILITARY ATTACK
0

LATE 1960s MIL.—
POP. ATTACK
0

144
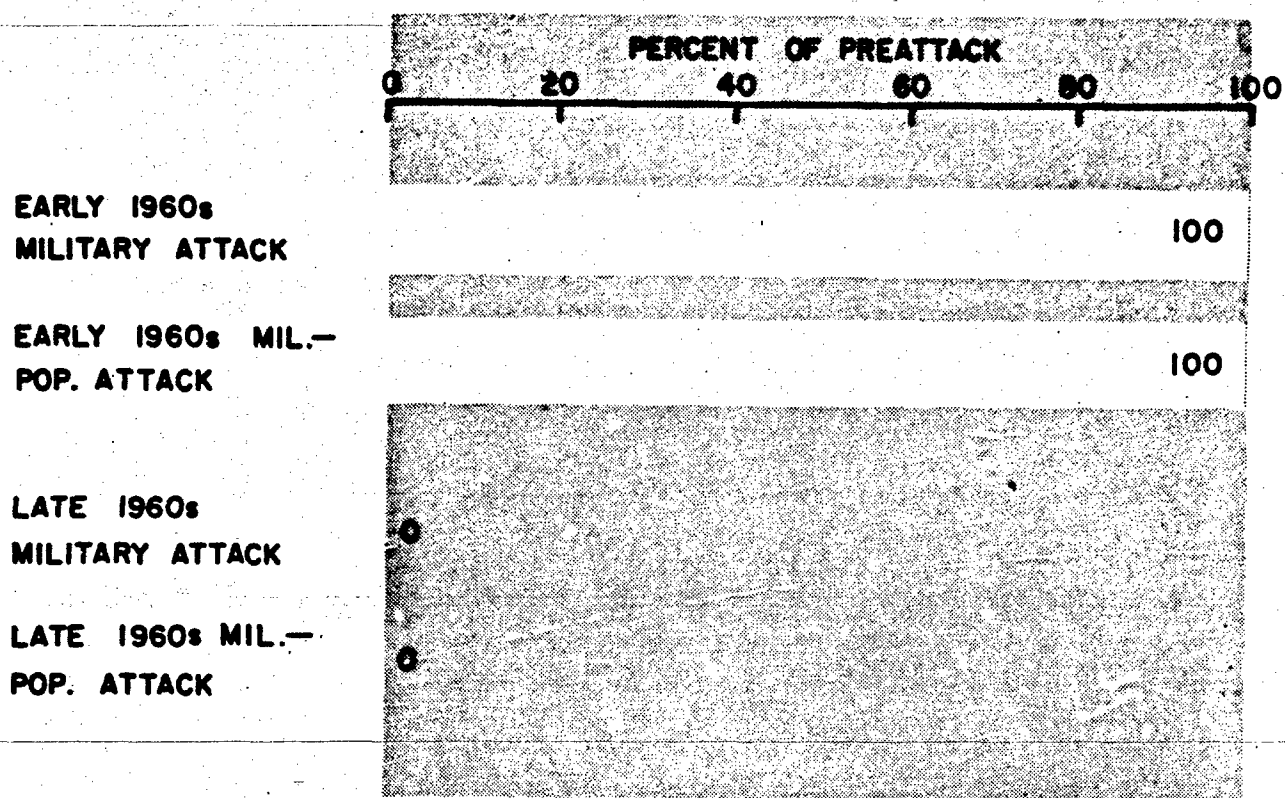
QUARRYING

LIMESTONE

MAGNESIUM

CRUSHING

LIMING MATERIALS

DISTRIBUTION

FARM USES
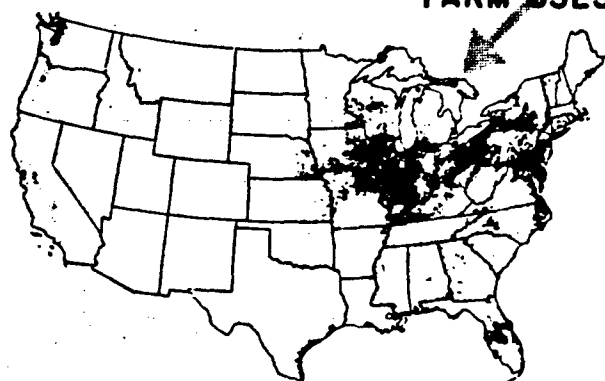
NON-FARM USES

Chapter IX

SOIL NUTRIENTS

Section 6: Liming Materials--Calcium and Magnesium

Background

A small percentage of calcium and magnesium is applied to the soil as fertilizer. Normal superphosphate, for example, contains 27 percent CaO (in the form of calcium phosphate and calcium sulfate). Liming materials, however, constitute the major source of calcium and almost the entire source for magnesium, as shown in Table 27.

Table 27

CALCIUM AND MAGNESIUM IN MATERIALS APPLIED TO THE SOIL, 1946
(Thousands of Tons)

	Calcium (CaO)	Magnesium (MgO)	Total Lime Nutrients	Total Weight of Material
Commercial Fertilizers	2,740	206	2,946	15,128
Liming Materials	12,210	2,405	14,615	29,462
Manure	--	1,062	1,062	1,370,110[1/]
Total	14,950	3,673	18,623	

1/ Manure production in 1947.

Source: Mehring, A. L., et al., Statistics on Fertilizers and Liming Materials in the United States, Statistical Bulletin No. 191, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, D.C., April 1957, Tables 32, 77, 81, 105, and 149.

In 1953, 21 million tons of liming materials were applied to the soil. This is about as much as the consumption of fertilizer materials in the same year and almost four times as much as the weight of primary nutrients (nitrogen, phosphates, and potash) applied to the soil.[1]

As with phosphorous and potassium, the amounts of the liming materials are expressed according to the equivalent weight of their oxides: calcium oxide (CaO) and magnesium oxide (MgO). The main uses of liming materials are to counteract acid soils in the eastern states, and as soil nutrients.

Calcium may be important to postattack agricultural production for more than its nutrient value because it has a depressant effect on the Strontium 90 uptake of plants. Calcium and strontium are close chemical relatives and therefore display similar reactive and absorptive characteristics. They tend to "compete" as ingredients in plant composition since they fulfill similar cell-building functions. Recent research has shown that additions of soil calcium do in fact have a depressant effect on the uptake of strontium. Nevertheless, the relationship is not a simple one, and is as yet imperfectly understood.[2] The effect seems to be enhanced in alkaline soils by the addition of acidifying materials such as gypsum, sulfur, liquid sulfur dioxide, sulfuric acid, aluminum sulfate, and ferrous sulfate.[3] Also several important nitrogen fertilizers, including ammonia, ammonium sulfate, ammonium nitrate, and urea have an acid reaction on the soil.[4]

Process Description

Since limestone decisively dominates agricultural liming materials (in 1953 limestone accounted for 97 percent of the liming materials

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[1] Statistics on Fertilizers and Liming Materials in the United States, Statistical Bulletin No. 191, U.S. Dept. of Agriculture, Washington, D.C., April 1957, Tables 105 and 149.

[2] Fowler, Eric B., "How Plant Foods Protect Plants," Plant Food Review, Summer, 1959.

[3] Mehring, A. L., "Special Fertilizers, Special Uses for Fertilizers, and Non-Fertilizer Sources of Plant Nutrients," Fertilizer Technology and Resources in the United States, K. D. Jacob, Editor, Academic Press Inc., New York, 1953, p. 414.

[4] Ibid., p. 415.

used by U.S. agriculture),[1] the subsequent analysis can be limited to this source.

Limestone is obtained from quarries and requires only crushing to the required particle size before agricultural use. Agricultural purposes account for only about 5 percent of consumption.[2] Neither the quarrying nor the processing involves any unusual techniques or requirements.

Vulnerability Summary

In 1954 there were 1,443 quarries producing crushed and broken limestone.[3] Most of them are remotely located and their losses from each of the four postulated attacks would be about the same as losses in the surrounding areas. Their critical resource is their work force, so losses are taken to be the same as loss by death or incapacitation of workers in the non-metropolitan population under the "available protection" condition. Surviving limestone productive capacity under these assumptions (explained in Chapter II) is shown in Figure 16.

Transportation requirements for calcium and magnesium are negligible because the sources are widespread (limestone occurs in some form in every state),[4] and quarries are usually located near markets to minimize transportation costs. Since the quarries are numerous and widespread, post-attack production should be entirely adequate in habitable areas.

1/ Mehring, "Special Fertilizers, Special Uses for Fertilizers, and Non-Fertilizer Source of Plant Nutrients," op. cit., p. 162.
2/ Preprint from Minerals Yearbook 1957, U.S. Bureau of Mines, Washington, D.C., p. 33. The largest user of crushed and broken stone is concrete and roadstone, which takes over 50 percent.
3/ Census of Mineral Industries: 1954, U.S. Bureau of the Census, Government Printing Office, Washington, D.C.
4/ U.S. Bureau of Mines, Minerals Yearbook 1956, Vol. 1, "Minerals and Metals 1958," p. 1106 reported sales from 44 states in 1956.

FIG. 16
AGRICULTURAL LIMESTONE PRODUCTION IN FIRST POSTATTACK YEAR

PERCENT OF PREATTACK

EARLY 1960s
MILITARY ATTACK — 97

EARLY 1960s MIL.-
POP. ATTACK — 89

LATE 1960s
MILITARY ATTACK — 70

LATE 1960s MIL.-
POP. ATTACK — 68

SYNTHESIS

FORMULATION

PESTICIDES

SULFUR

PLANT MATERIALS

INSECTS
MITES

WEEDS

FUNGI

FUMIGATION
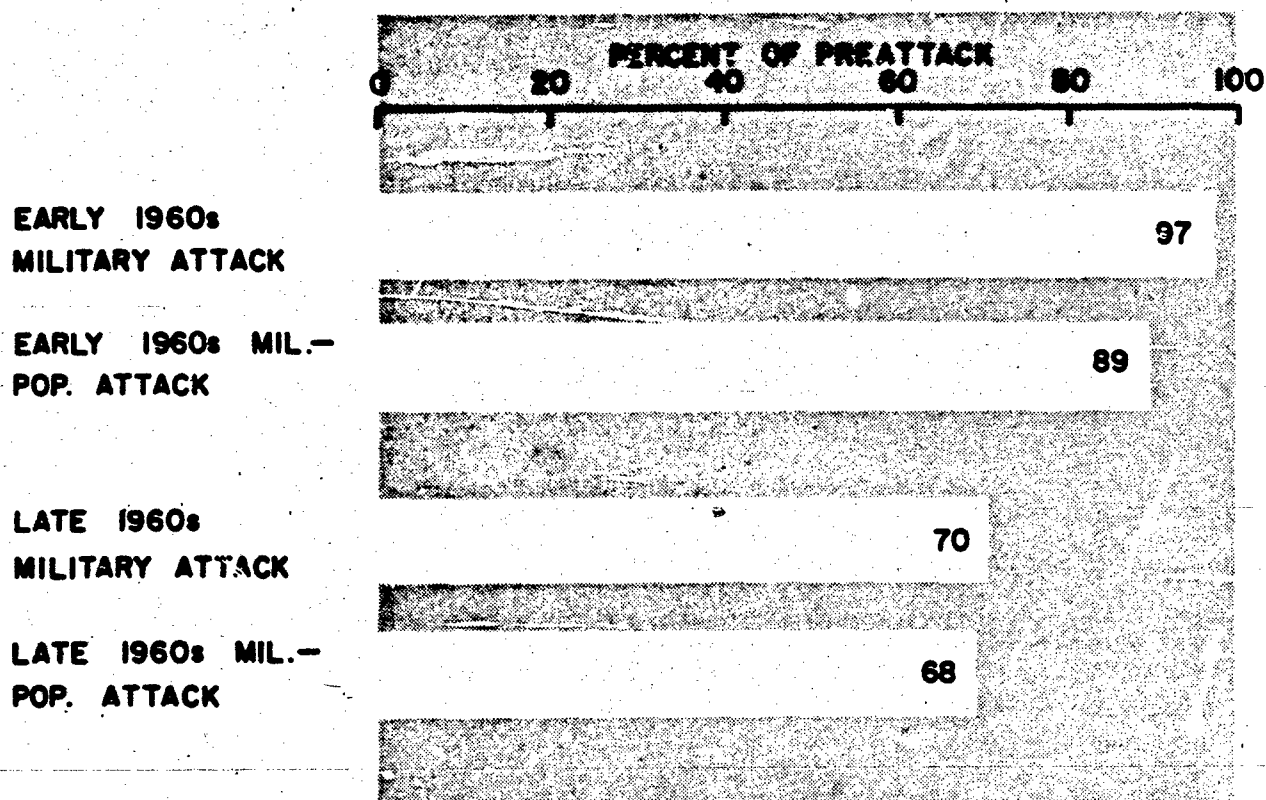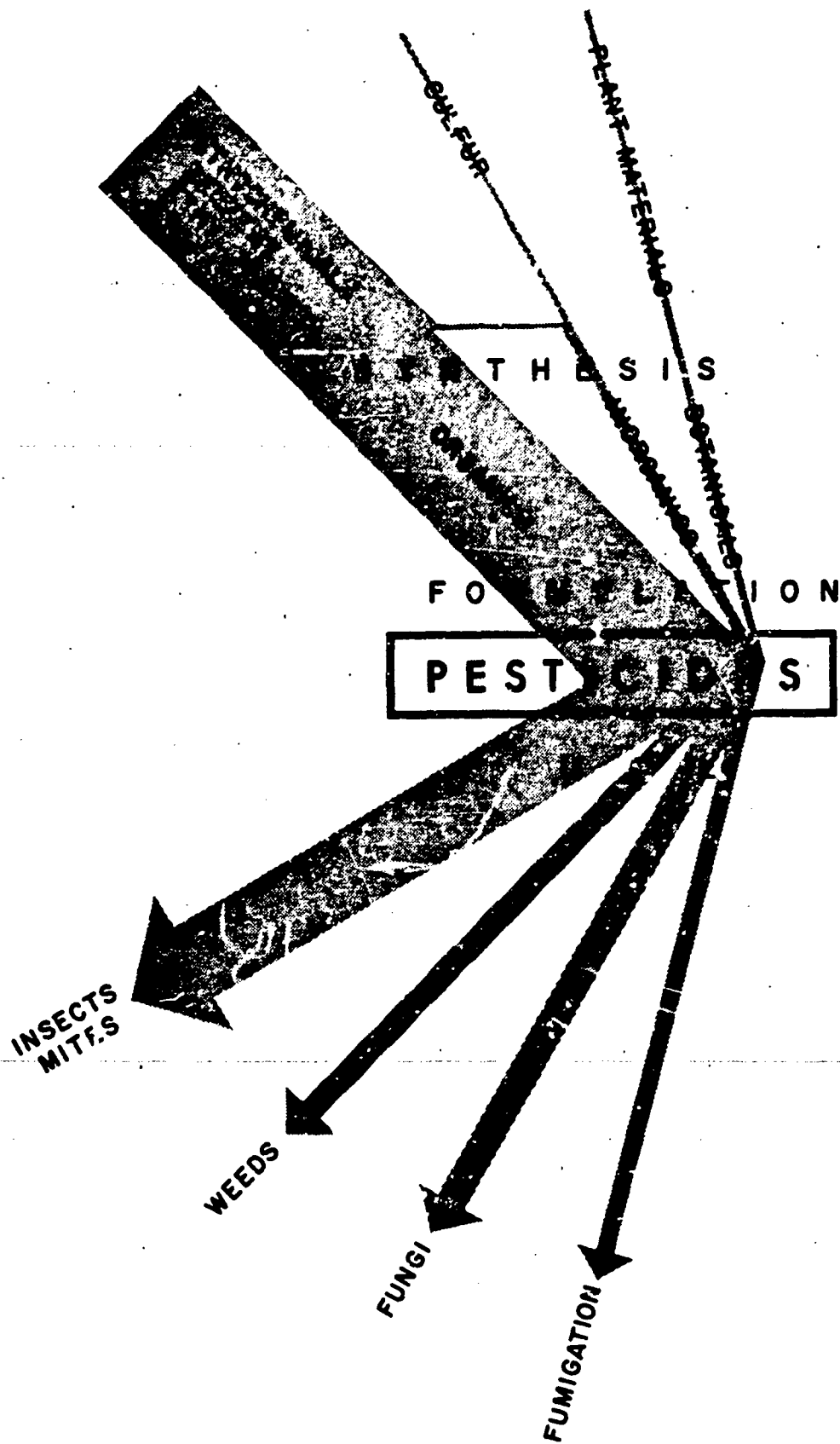
Chapter X

PESTICIDES

Background

Insects, plant diseases, weeds, and parasites are a serious problem to farming; annual losses attributable to these various pests are over 10 billion dollars (see Table 28), and amount to one quarter of potential production. Since pest control agents were being used to lessen the losses during the period over which these data apply (1942-51), the absence of any pesticides would clearly have resulted in considerably greater losses. In Part I of this study, first-year effects of a complete cutoff of pesticides were estimated as reducing current crop production by 27 percent and livestock production by 9 percent.[1]

In the effort to control the damage of various pests, larger and larger quantities of chemicals have been sold. The total pesticides market amounted to only $40 million in 1939, but by 1960 sales amounted to about $600 million.[2] New pesticides are being added continuously, and old ones are being phased out as superior products or pest-resistant crops are introduced and as pests develop immunities. Pesticides consist mainly of insecticides, herbicides, and fungicides.

Insecticides can be classified according to four general types: chlorinated insecticides, phosphorus insecticides, inorganic insecticides, and botanicals. Process analyses of each type except the phosphorus insecticides (malathion, parathion, etc.) are given below. Herbicides, both organic and inorganic, are used for three purposes: (1) as weed

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[1] See Chapter II of this report, Figures 2 and 3.
[2] Tenth Annual Report of the Activities of the Joint Committee on Defense Production, Activities of the Dept. of Agriculture, Exhibit 4, page 163, GPO, Washington 1961.

Table 28

ESTIMATED AGRICULTURAL LOSSES FROM VARIOUS PESTS, AVERAGE ANNUAL
1942-51

Cause of Loss	Loss in Value	
	Amount (millions of dollars)	Percent of Potential Production[1]
During Production of Crops		
Diseases	2,847	6.9%
Insects	1,942[2]	4.7
Weeds	1,789	4.4
Subtotal, Crops	6,578	16.0%
During Production of Pastures and Ranges		
Diseases	419	1.1
Grasshoppers	89	0.1
Weeds and brush	471	1.2
Subtotal, Pastures and Ranges	979	2.4
Farm Storage Losses to Crops, Pastures, and Ranges Due to Insects	217 217	0.5 0.5
Total Losses to Crop Values	7,774	18.9%
Losses to Livestock, Poultry, and Their Products		
Diseases	1,753	4.3
Insects	508	1.2
Parasites	340	0.8
Total Losses to Livestock Values	2,601	6.3
Total Losses to Crops and Livestock	10,375	25.2%

1/ I.e., the value of crops and livestock that would have been produced had the losses shown (plus certain additional other non-pest losses) not occurred. Value of average annual production for the period covered was $27.6 billion.

2/ Includes crop losses of $991 million from about 75 insects on which detailed estimates were made. From this sample, it is estimated that the loss from the remaining several thousand species attacking U.S. crops was $951 million. Total losses to crops, livestock, forests, fabrics, households, and buildings from all insects have been estimated at $3,600 million.

Source: *Losses in Agriculture*, Agricultural Research Service, ARS-20-1, U.S. Dept. of Agriculture, Washington, D.C., June 1954, pp. 86, 130, 131, 132, 134, 147, 152, 187.

killers for field, horticultural, and forage crops; (2) as brush killers; and (3) as soil sterilants.[1] Fungicides include antibiotics[2] as well as organic and inorganic types, but only inorganics are examined in detail here.

None of the less widely used pesticides are discussed in detail, but they should be mentioned. Soil fumigants are used for treating nematodes and soil-borne diseases. Miticides are used to control mites that destroy crops by sucking juices from plants (particularly from cotton, fruit, nut, and vegetable crops). Space fumigants are used to control insect infestation of stored crops, particularly grains. Rodenticides are used in combination with nest destruction and elimination of food sources for rat control. Repellents are used against fleas, chiggers, mites, and mosquitoes. Listings of major individual pesticide products can be found in Chemical Week.[3]

Process Description

Unlike fertilizers, pesticides do not lend themselves to a vulnerability study that focuses attention on a few standard industrial processes. There is a vast array of pesticides, and processing tends to be designed to the particular product. Processing is often done by a series of plants in different locations, so that the manufacture of pesticides comprises a vast and complicated structure of interconnections that involves the entire chemical industry.

The nature of the problem is perhaps best related by example.[4] Shell Chemical Corporation and Velsicol Corporation are the only producers of a series of insecticides (aldrin, dieldrin, endrin, chlordane, and heptachlor) derived from cyclopentadiene. Each company has only one plant at which these insecticides are made; the Shell plant is in Denver, and the Velsicol plant is in Marshall, Illinois. The source for the

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1/ Another herbicide group called dessicants and defoliants (used largely in the defoliation of cotton) is omitted here.

2/ The Chemical Industry Facts Book, 2nd Ed., Manufacturing Chemists Assoc., Inc., Washington, D.C., 1955, p. 95.

3/ Fischer, Carl D., "Pesticides: Past, Present, and Prospects," Chemical Week, October 27, November 3, and November 17, 1956.

4/ From Mr. Leo Gardner, Vice President and Director of Research, California Spray Chemical Company.

cyclopentadiene used in their manufacture is currently restricted to Standard Oil of New Jersey's Bayonne refinery. Moreover, an intermediate process is carried out at Hooker Electro-chemical Company at Niagara Falls before shipment to Shell and Velsicol. Hence, there are not two plants but four that must be studied. Loss of the prior processing facilities, particularly the Standard Oil plant, could be more serious than loss of either the Shell or Velsicol plants. However, if the prior processes were cut off, substitute suppliers might be found rather easily (at least in this case).

A comprehensive process description of pesticides would include several major steps: (1) the raw materials (coal, petroleum, minerals, and agricultural products), (2) their initial processing during which such basic chemicals as benzene, ethylene, and chlorine are prepared, (3) the processing of these materials by the large basic synthesizers such as Dow, Monsanto, Rohm and Haas, and Du Pont, (4) the production of the end-product chemical by the pesticide producers themselves, and finally (5) the formulators who take the pesticide and process it into a form that can be applied economically by the farmer. In this report, the second, third, and fourth steps are emphasized.

Step (1), the study of the raw materials, involves problems too remote (and from a cost standpoint too insignificant) to consider in this assessment of complex chemicals. Certain raw materials used in pesticides such as sulfur are considered elsewhere in the report. Step (2), the study of basic chemicals, is carried through below for benzene, ethyl alcohol, and chlorine, which are necessary ingredients in several important pesticides. Steps (3) and (4), the study of processing requirements for end-product chemicals, are also discussed in this chapter. Step (5), the study of operations by the formulators, is not considered in detail here, because formulators are widely dispersed in market areas rather than centralized in urban areas and their function is largely servicing and marketing rather than processing.

Of all the steps, the operations of the basic synthesizers (Step 3) are probably the most vulnerable. But even these are too diverse and complicated an industry aggregate to be described in great detail in this report. However, a partial examination is of value, not only for assessing vulnerability of pesticides, but also for viewing a representative sample of the entire chemical industry. The vulnerability study which follows, therefore, examines some of the major pesticide compounds on an individual basis and describes the chemical inputs on which they depend. Individual changes in distribution, capacity, and production practices will certainly occur before 1965, but the type of problems faced by the industry will probably remain.

Vulnerability Assessment of Basic Pesticide Chemicals

1. Benzene

DDT and BHC, both of which are analyzed later in this chapter, are the largest pesticide users of benzene. This chemical is a petroleum product derived from straight-run gasolines and napthas.[1] Benzene is also obtained as a by-product in the manufacture of coke, where it is recovered from the coal tar and light oil fractions. Prior to 1950, coke ovens were the only important source of benzene, but with the Korean War, demand for aromatic products increased beyond that which the coke oven operators could satisfy. Since then petroleum has become a full partner in the business, accounting for 50.1 percent of the benzene produced in the United States in 1958.[2] Probably the 1965 production of 475 million gallons of benzene will be divided as follows: coke, 46 percent; petroleum, 43 percent; imports, 11 percent.[3]

Since much of the refinery-reformed benzene is not separated at present but is used to enrich gasoline stocks, the potential benzene supply from petroleum sources is much greater than the current supply.[4] In 1957 there were over 150 catalytic reformer units in operation or under construction in the United States, but only 20 to 25 were used for the production of aromatic hydrocarbons.[5] Clearly this source, should it survive an attack, would be able to satisfy most conceivable postattack benzene requirements. However, there is a possibility that the 300 refineries in the United States might be individually targeted to knock out oil production. In this event, the entire petroleum production of benzene would be destroyed and coke oven benzene would be the sole surviving domestic source.

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[1] Hansen, Neil, and Deane Grovers, "Aromatics in Trouble," Chemical Week, March 7, 1959, p. 56.

[2] Mineral Industry Surveys, Mineral Market Report, M.M.S. No. 2924, U.S. Bureau of Mines, Washington, D.C., June 1959, p. 20.

[3] Oil, Paint, and Drug Reporter, October 25, 1958, p. 13.

[4] Faith, Industrial Chemicals, op. cit., p. 58.

[5] Ibid.

Two types of ovens are used to produce coke: slot-type ovens and beehive ovens. Only from the former are by-product chemicals recovered. In 1957 there were 51 coke oven gas and coal tar plants producing by-product benzene.[1] Although in general these are located in proximity to the steel industry and hence to population centers, there are a sufficient number of the coke plants remotely located to easily satisfy the DDT and BHC benzene requirements following even the most severe attacks if their priorities for limited production are sufficiently high. However, DDT and BHC are only two of several important users of benzene over which postattack production must be distributed.[2]

Demand for DDT has been projected to increase from the 1957 level of 13 million gallons to 18 million gallons in 1965, and demand for BHC from 3.5 million gallons in 1957 to 4.5 million gallons in 1965.[3] Together these two insecticides would require only 5 percent of total forecast benzene production.

2. Ethyl Alcohol

This basic chemical is used in the preparation of DDT, malathion, methoxychlor, and other insecticides. In 1959, 88.5 percent of industrial ethyl alcohol was produced synthetically from ethylene, and 11.5 percent was produced by fermentation.[4]

Since petrochemicals are such a vigorously growing industry, ethylene (and ethyl alcohol) plant locations for 1965 are difficult to estimate.[5] However, on the basis of present ethyl alcohol plant locations (9 plants in 6 states)[6] synthetic ethyl alcohol losses from all four

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1/ Ibid., pp. 145-146.
2/ Other users of critical importance include phenol, aniline, chlorobenzene, and maleic anhydride.
3/ By linear interpolation of the 1968 forecasts made by Hansen and Groves, "Aromatics in Trouble," op. cit., p. 58.
4/ Chemical Economics Handbook, Stanford Research Institute, 1960, Table 644.301.
5/ Chemical Week, May 9, 1959, p. 92.
6/ James W. Bradley, Robert J. James, and Richard F. Messing, "Ethylene: Technology Paints and Market Picture," Chemical Engineering, January 27, 1958, p. 93.

postulated attacks would be extensive. Losses would be even greater if refineries were targeted, because the petrochemical industry is geographically concentrated and highly interconnected. In fact, there are only two synthetic ethanol plants that are located away from both oil refineries and major metropolitan areas.

Since the large fermentation plant in Philadelphia (containing 50 percent of total national capacity in 1956) would also be lost in the population attacks, surviving industrial ethyl alcohol sources following either the early 1960's or late 1960's military-population attack might be small. Distilleries, however, could be utilized as a stop-gap measure, and temporary fermentation plants utilizing any abundant material that will ferment (such as molasses, cereal grains, or potatoes) could probably be set up as required. Losses sustained by normal producers of ethyl alcohol should not, therefore, prevent postattack production from at least satisfying the minimal quantities required by priority demands.

3. Chlorine

Chlorine is a basic ingredient in the chlorinated insecticides; for example, 1.2 tons are required to produce the chloral used in a ton of DDT.[1]

About 85 or 90 percent of all chlorine is produced by the electrolysis of common salt, a process that requires about 3,000 kwh of electricity per ton.[2] By-products of this process are sodium hydroxide (caustic soda) and hydrogen (used for ammonia synthesis as explained in Section 3 of Chapter IX).

Chlorine is produced in over 80 plants in the United States, and over half of the amount produced is consumed at the plant site. It is expensive and difficult to transport because of its toxicity and corrosiveness and the consequent necessity for special containers. Nevertheless, many plants are located near enough to power sources or salt deposits to take advantage of low electricity and raw material costs. The resultant pattern is a rather wide distribution of facilities,

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[1] Faith, _Industrial Chemicals_, _op_. _cit_., pp. 252 and 321.
[2] Ibid., pp. 257-264.

correlated to a large extent with the locations of consuming chemical industries, but operationally dependent on the availability of abundant electric power.

Vulnerability of the chlorine industry can therefore be estimated by viewing the vulnerability of both chlorine-related chemical plants and electrical power facilities, as in Table 29.

The estimates indicate that chlorine and chlorine-related plant locations are equally or more vulnerable than electric power supplies to most types of attacks. In general, then, chlorine supplies can be expected to be maintained in proportion to the demand of dependent chemical producers.

Table 29

VULNERABILITY OF CHLORINE PRODUCTION

	Percent of Electricity Available[1]	Percent of Chlorinated Chemical Plants Surviving[2]
Early 1960's Attacks		
Military	100%	100%
Military-Population	60	25
Late 1960's Attacks		
Military	80	85
Military-Population	30	10

[1] From Figure 10. Availability of power for chemical plants would generally be similar to availability for farming areas, since generation rather than transmission is likely to be the major problem in both cases.

[2] Approximate average of estimates shown in Table 34 for the cyclopentadiene family, DDT, and BHC.

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Vulnerability Assessment of Selected Pesticides
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The pesticides that have been selected for special study in the
following pages represent over 60 percent by weight of the 26 major
pesticidal chemicals whose 1958 production was reported by the Commodity
Stabilization Service.[1]/ Although the list of 26 by no means exhausts
all the important pesticidal chemicals, it does include most of the
major types, so that the following analysis is representative of the
industry.

1.   Insecticides
     _____

     a. Chlorinated Insecticides--the Cyclopentadienes and
         _____
         Toxaphene
         _____

         The domestic consumption of the five cyclopentadiene-derived
insecticides--aldrin, chlordane, dieldrin, endrin, and heptachlor--to-
gether with toxaphene, totaled 73.3 million pounds during the 1958-59
crop year.[2]/ This total was nearly as great as the domestic consumption
of DDT, the largest selling organic pesticide, in the same period.

         Of the four plants described in the example of cyclopentadiene
insecticide production, three are strategically located. Bayonne is a
part of the Newark-Elizabeth-Jersey City complex, Denver is the major
metropolitan area in Colorado, and Niagara Falls is a part of the Buffalo-
New York metropolitan area. Loss of all three of these plants and at
least two of the three production stages could therefore be expected
under an attack directed at population targets. This would mean loss
of the entire output of the whole family of cyclopentadiene-derived
insecticides. Early development of an alternative source would be par-
ticularly unlikely if petroleum refineries were targeted separately.

1/ Commodity Stabilization Service, The Pesticide Situation for 1959-60,
    op. cit., p. 2.
2/ Ibid., p. 8.

b. Chlorinated Insecticides--DDT

Prior to World War II, farmers depended almost exclusively on inorganic insecticides to control insect pests, but with the appearance of DDT as a commercial insecticide, this changed rapidly. DDT was by far the largest selling organic pesticide in the crop year 1958-59 (and has been since World War II) when its domestic consumption was about 78.7 million pounds.[1] In addition, 74.9 million pounds were exported.[2] If the month of highest production in 1959 is taken as a basis, the annual capacity to produce DDT would exceed 177 million pounds,[3] so production amounted to 87 percent of capacity. In 1956 the Montrose Chemical Corporation plant at Torrance, California, was reported to be producing DDT at an estimated rate of 57 million pounds per year, or 40 percent of the total.[4] Thirteen other DDT plants are listed in Faith's _Industrial Chemicals._[5]

DDT is synthesized by the reaction of monochlorobenzene and chloral in the presence of sulfuric acid (which acts as a dehydrating agent). Monochlorobenzene is used for a variety of organic chemical processes so that the DDT demand for it amounted in 1955 to only 25 percent of total production.[6] On the other hand, 99 percent of chloral production[7] was used in the manufacture of DDT. Some DDT manufacturers produce their own monochlorobenzene and chloral; others purchase chloral from outside sources.

The comparatively small number of chloral plants (five compared with nine monochlorobenzene plants) suggests that they are a vulnerable feature of the DDT production system. Although none of the chloral plants are located in proximity to military bases, all except the Henderson, Nevada, plant are located in or adjacent to major metropolitan areas. Hence, losses to four of the five plants can be anticipated under attacks directed at population targets. Moreover, loss of production from the Henderson plant could also be anticipated if it were blanketed by radioactive fallout after the late 1960's attacks.

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[1] Ibid., p. 8.
[2] Ibid., p. 5.
[3] Ibid., p. 11.
[4] Fischer, "Pesticides: Past, Present, and Prospects," op. cit., p. 62.
[5] Faith, Industrial Chemicals, op. cit., p. 325.
[6] Ibid., p. 268.
[7] Ibid., pp. 254, 256, 270.

The monochlorobenzene plants are both more numerous and more
widely dispersed around the country than the chloral plants; they also
are less intensively devoted to DDT production. Therefore, production
of necessary quantities could be more easily maintained if deemed essen-
tial. Vulnerability of benzene, ethyl alcohol, and chlorine are discussed
above, and sulfur is discusses in Section 4 of Chapter IX. None of these
essential input materials would appear to be in short supply.

Although loss of the DDT Montrose plant at Torrance, California,
could be expected under a population attack on Los Angeles, DDT plants
are also more numerous (14 in 9 states) and generally less critically
located than the chloral plants. Table 30 shows the estimated postattack
DDT capacity following each attack, in which the major restriction is
limited chloral supplies.

Table 30

PRODUCTION OF DDT IN FIRST POSTATTACK YEAR

Early 1960's Attacks

Military	100%
Military-Population	20

Late 1960's Attacks

Military	70
Military-Population	0

c. Chlorinated Insecticides--BHC

Benzene hexachloride, often called BHC or 666, is another of
the chlorinated organic insecticides. BHC is prepared by chlorinating
benzene in the presence of ultraviolet light, then concentrating the
product by distillation and fractional crystallization. Its gamma isomer
provides the toxic properties, and when the product contains 99 percent
of the gamma isomer it is known as lindane. On a gamma isomer basis,
4.3 million pounds of BHC were used domestically during the 1958-59 crop
year, and an additional 1.9 million pounds were exported.[1] Between

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[1] Commodity Stabilization Service, The Pesticide Situation for 1959-60,
op. cit., p. 8.

65 and 85 percent of production was used on the cotton crop to control t. boll weevil.[1] BHC is used where DDT has not been effective.[2]

There are 20 plants producing BHC in the United States;[3] they are widely enough dispersed in 14 states so that some should survive even the worst attack. Both benzene and chlorine are necessary for BHC production; but neither of these basic chemicals is expected to be in relatively short supply. While losses to benzene capacity would be extensive for the military-population series of attacks, especially if refineries were separately targeted, these losses would probably not be great enough to constrain BHC manufacture. Rather, postattack BHC production would rest on the survival of the BHC plants themselves. Table 31 shows the estimated postattack production of the BHC plants.

Table 31

PRODUCTION OF BHC IN FIRST POSTATTACK YEAR

Early 1960's Attacks

Military	100%
Military-Population	60

Late 1960's Attacks

Military	85
Military-Population	25

d. Inorganic Insecticides--Calcium Arsenate and Lead Arsenate

Production of calcium arsenate, which in 1956 amounted to 27.1 million pounds, declined in 1958 to 10.4 million pounds, as other materials were introduced to control resistant strains of the boll weevil on cotton. Production of lead arsenate, on the other hand, remained constant in recent years, with 1958 production being nearly 15 million pounds.[4]

1/ Faith, Industrial Chemicals, op. cit., p. 150.
2/ Ibid.
3/ Ibid.
4/ Commodity Stabilization Service, The Pesticide Situation for 1959-60, op. cit., p. 14.

By comparison with organic compounds, the preparation of these inorganic compounds is simple. The raw materials for calcium arsenate are calcium carbonate, arsenic trioxide, and water. Limestone is converted from calcium carbonate to calcium hydroxide by burning it and then adding water. Arsenic trioxide, a by-product from the roasting of mineral ores, is oxidized to its pentoxide form (usually with nitric acid). When the calcium hydroxide and arsenic pentoxide are brought together in water, the reaction yields calcium arsenate.[1]

Lead arsenate is prepared by bringing together litharge (lead oxide) and arsenic pentoxide (prepared according to the procedure in the preceding paragraph) in water solution and in the presence of acid catalysts. Lead arsenate forms and precipitates out.[2] There are nine leading producers of each of these compounds;[3] plants are widely spread throughout all consuming areas in the country.[4]

Since calcium arsenate and lead arsenate are so easily prepared, temporary postattack facilities could probably be set up as required to replace lost plants or expand the capacity of lost plants. No specific vulnerability estimate for these chemicals has been made.

e. Botanicals--Rotenone and Pyrethrum

The domestic consumption of pyrethrum and rotenone for the crop year 1957-58 was 8.6 and 4.1 million pounds, respectively.[5]

Rotenone and pyrethrum, like most botanical insecticides, are derived from imported products which are ground or otherwise treated to obtain the extract of the wood, root, flower, or seed (as the case may be) by manufacturers here in the United States. Vulnerability of the sources themselves (mostly in tropical areas) is probably nil, but product

1/ Kirk, Raymond E., and Donald F. Othmer, Encyclopedia of Chemical Technology, Vol. 7, Interscience Encyclopedia Inc., New York, 1951, p. 884.
2/ Ibid., p. 885.
3/ Fischer, Carl D., Chemical Week, Oct. 27, 1956, p. 74.
4/ Statement of Mr. Robert Cone, California Spray Chemical Corporation.
5/ The Pesticide Situation for 1958-1959, Commodity Stabilization Service, Washington, D.C., April 1959, p. 4.

availability depends on the reliability of transportation. If imports were cut off, synthetic domestic sources might, if available, meet much of the demand for botanicals (e.g., allethrin could fulfill many of the functions of pyrethrum).

2. Herbicides

Two herbicides have been selected for special study: the leading organic herbicide, 2,4-D, and the leading inorganic herbicide, sodium chlorate.

2,4-D is prepared by reacting 2,4-dichlorophenol and monochloroacetic acid together with sodium hydroxide for several hours under controlled conditions, after which time the product is acidified by adding dilute hydrochloric acid.[1] The 2,4-D is removed by crystallization.

Although the manufacturing plant requirements for 2,4-D are "comparatively simple"[2] for an organic pesticide, peacetime production is concentrated among a few producers. However, postattack recovery conditions could be expected to change economic requirements so that lack of an established position or experience in this process need not prevent a company from manufacturing 2,4-D if raw materials are available and the demand is high.

Since the three producers of 2,4-dichlorophenol[3] and two of the six producers of monochloroacetic acid[4] are among the seven producers of 2,4-D, vulnerability of these input chemicals would be similar to that of the 2,4-D plants themselves. There are nine 2,4-D plants in eight states.[5] Only two of them are not in or adjacent to major metropolitan centers; consequently, losses in the military and population series of attacks can be expected to seriously disrupt 2,4-D production. Postattack capacity under these attacks would probably be 25 percent or less of preattack capacity.

1/ Faith, Industrial Chemicals, op. cit., p. 326.
2/ Ibid., p. 329
3/ Synthetic Organic Chemicals, Report No. 203, 2nd Series, U.S. Tariff Commission, Washington, D.C., 1958.
4/ Ibid.
5/ Faith, Industrial Chemicals, op. cit., p. 326.

Although sodium chlorate is not a particularly essential pesticide, it is an example of a product that is produced by electrolysis. Sodium chlorate is made in a special cell of saturated sodium chloride solution that has been acidified with hydrochloric acid. The electricity requirement per ton of sodium chlorate is high--5,100 kwh.[1] Other than the high electricity requirement and the use of a graphite anode, which is consumed, the process does not appear to have any critical inputs.

Only 30 percent of the annual production of sodium chlorate is currently used as a herbicide or defoliant; most of the remainder is used to bleach pulp.[2] A greater proportion of sodium chlorate could be shifted to herbicidal uses should postattack conditions require. If the five plants (located in five states)[3] were of equal size, surviving capacity under each of the postulated attacks would be as estimated in Table 32.

Table 32

SODIUM CHLORATE PRODUCTION IN FIRST POSTATTACK YEAR

Early 1960's Attacks

Military	100%
Military-Population	60

Late 1960's Attacks

Military	80
Military-Population	20

3. Fungicides

On a quantity basis, copper sulfate and ground sulfur are the two most widely used fungicides. A third or more of total copper sulfate production normally is used for agricultural purposes, and about a third

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1/ Ibid., p. 665.
2/ Ibid., p. 668.
3/ Ibid., p. 670.

of this portion is used as a fungicide (most of the rest is applied to copper-deficient soils, particularly in the Florida citrus area).

As a fungicide, copper sulfate is generally used in solution with hydrated lime, and the resulting material is known as Bordeaux mixture. Hydrated lime is obtained by mixing quicklime, which is obtained from limestone, with water. Limestone deposits and lime manufacture are widely spread throughout the United States, so that supplies of hydrated lime should pose no problem.

Copper sulfate manufacture is not too widely spread, but the process is so simple that makeshift plants could be set up as required in a post-attack emergency. Copper sulfate is obtained by reacting copper oxide (either from copper ores or scrap copper) with sulfuric acid. Evaporation and crystallization follow, yielding the solid crystalline product. Approximately 20 to 30 percent of the copper sulfate marketed comes from the refining of copper ores; the remainder is from reacting scrap copper with dilute sulfuric acid.[1] These scrap copper plants can be "of almost any size, and frequently operate with cheap reconditioned equipment."[2] Since 20 to 45 percent of U.S. production is currently exported,[3] it would seem that the industry could sustain fairly severe losses before being unable to meet domestic demands; however, postattack use might conceivably exceed preattack use because copper sulfate is more easily produced than organic fungicides and might therefore be used as a substitute.

Ground sulfur presents virtually no problem. In 1957, 150 million pounds of sulfur were used as a fungicide,[4] but this quantity is so small in comparison with over-all sulfur production (17,700 million pounds in 1958)[5] that the fungicide requirement for sulfur can easily be met under all of the postattack conditions.[6]

1/ Faith, Industrial Chemicals, op. cit., p. 295.
2/ Ibid.
3/ Ibid, p. 296.
4/ Chemical Economics Handbook, Stanford Research Institute, December 1958, pp. 571-573.
5/ Haynes, William, "Changing World Sulfur Balance," Chemical Week, May 16, 1959, p. 111.
6/ The vulnerability of sulfur is discussed in Section 4, Chapter IX. In general, domestic production or imports should be adequate to meet essential postattack requirements.

Vulnerability Summary

The preceding discussion of the vulnerability characteristics of some of the more important pesticides is largely limited to plant location considerations. Although the vulnerability of some of the prior process plants has sometimes been included in these estimates, the intricate system of interconnections that exists within the chemical industry has prevented tracing the processing back more than one or two stages. An approximate measure of losses sustained by the chemical industry is presented in Table 33, which shows the percentage of employees available postattack in the chemical industry and in the petroleum and coal industries. Available workers are considered to be those located in areas receiving less than 3,000 r/hr at H plus 1 hr. This assumes that workers who are capable of returning to the job have protection from fallout effects equivalent to that of a home basement (i.e., "available shelter" condition).

Table 33

EMPLOYEES AVAILABLE IN CHEMICAL, COAL, AND
PETROLEUM INDUSTRIES IN FIRST POSTATTACK YEAR

	Chemical Industry	Petroleum and Coal Industries
Early 1960's Attacks		
Military	95%	95%
Military-Population	33	24
Late 1960's Attacks		
Military	79	77
Military-Population	22	14

Manpower availability rates are high enough after either of the military attacks to indicate that critical postattack demands can be met, but they are quite low following the military-population attacks. Indeed, following either of these attacks, the availability factors given for many of the aforementioned pesticides perhaps should be reduced,

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as supporting chemicals vital to their manufacture probably would not be available.[1] Possible shortages of other vital inputs (electric power, fuel, spare parts) can likewise be expected to interfere with postattack pesticide production, but they would probably not be as constraining in most cases as supplies of basic chemicals. The summary of losses given in Table 34 repeats the estimates of plant losses given in the foregoing process description in this chapter.[2]

The existence of excess capacity and the possibility of substitution among pesticide types have also not been considered rigorously, but their influences would partially offset the plant losses and secondary effects mentioned above. Over-all estimates of domestic availability of pesticides (based on preattack domestic consumption levels) are shown in Figure 17.

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[1] Among the basic chemicals are benzene, ethyl alcohol, chlorine, phenol, ammonia, methane, ethylene, butadiene, bromine, fluorine, carbon disulfide, and cyclopentadiene.

[2] The losses are based on plant losses only. The estimates are rough since they have been made without benefit of individual plant capacity figures.

Table 34

PRODUCTION OF SELECTED PESTICIDES IN FIRST POSTATTACK YEAR

Pesticide	1958 Production [1] (millions of lb)	1957-58 Pesticides Domestic Consumption [2] (millions of lb)	Surviving Production Capacity			
			Early 1960's Military	Attacks Mil.-Pop.	Late 1960's Military	Attacks Mil.-Pop.
Cyclopentadiene Family [3]	98.3	78.8	100%	0%	100%	0%
DDT	143.2	66.7	100	20	70	0
BHC [4]	6.2	5.5	100	60	85	25
Calcium Arsenate	9.0	9.0	Temporary facilities can be set up in emergency			
Lead Arsenate	11.8 [5]	12.0 [5]	"			
Rotenone	4.8 [6]	4.1	Dependent on continued imports			
Pyrethrum	7.0 [6]	8.6	"			
2, 4-D Acid	28.5	21.3	100	25	100	20
Sodium Chlorate	134.5	n.a.	100	60	80	20
Copper Sulfate	97.2	75.1	Temporary facilities can be set up in emergency			
Sulfur	17,700.0 [7]	150.0 [8]	Pesticide requirements can be provided after each attack			

[1] The Pesticide Situation for 1958-59, Commodity Stabilization Service, April 1959, p. 3.
[2] Ibid., p. 4
[3] Includes toxaphene to avoid disclosure of individual plant capacities.
[4] Gamma equivalent basis.
[5] Preceding year's figures.
[6] Imports. Chemical Economics Handbook, Stanford Research Institute, December 1965, p. 573.37.
[7] Haynes, op. cit., pp. 571-573.
[8] Stanford Research Institute, op. cit., p. 573.71.

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FIG. 17
PESTICIDE PRODUCTION IN FIRST POSTATTACK YEAR

PERCENT OF PREATTACK

0   20   40   60   80   100

EARLY 1960s
MILITARY ATTACK
                                        100

EARLY 1960s MIL.-
POP. ATTACK
                        40

LATE 1960s
MILITARY ATTACK
                                70

LATE 1960s MIL.-
POP. ATTACK
                20

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WHEAT POTATO

FIELD CORN

SUGAR
BEET

VEGETABLE
ALFALFA
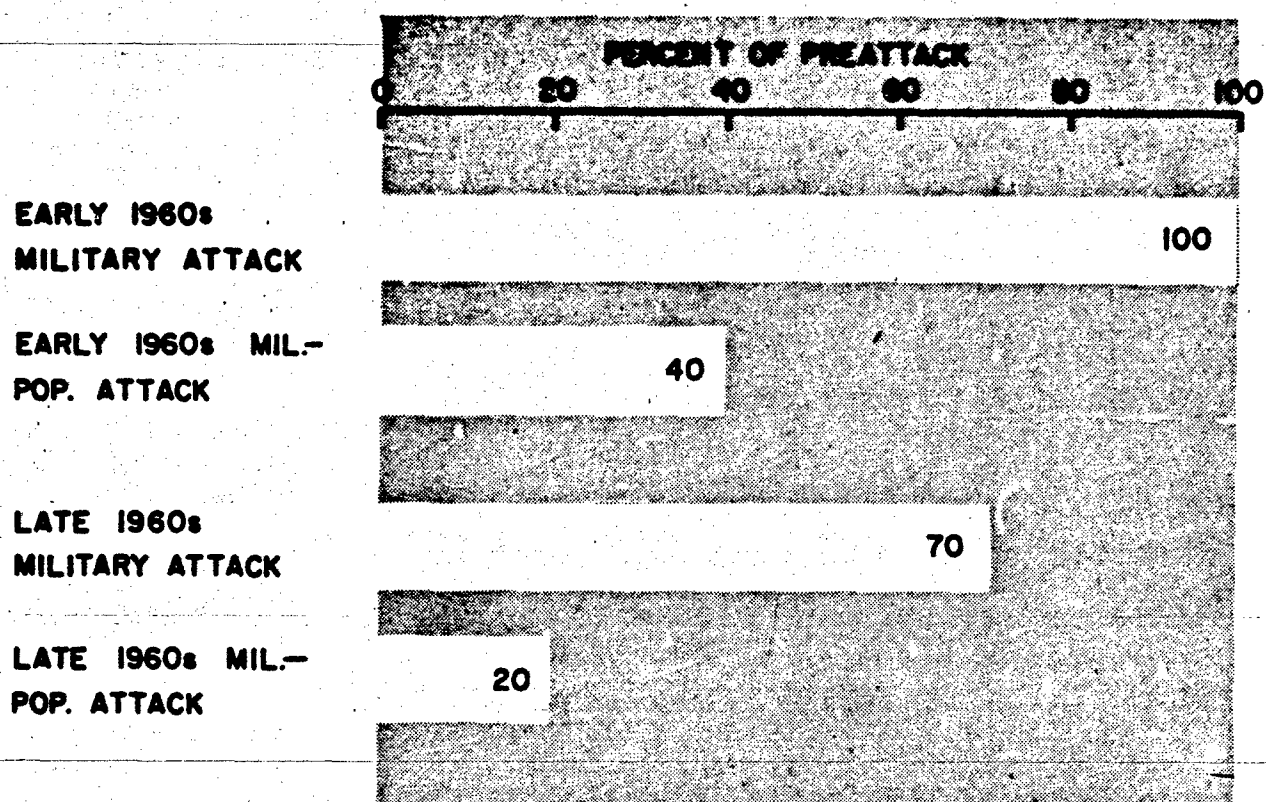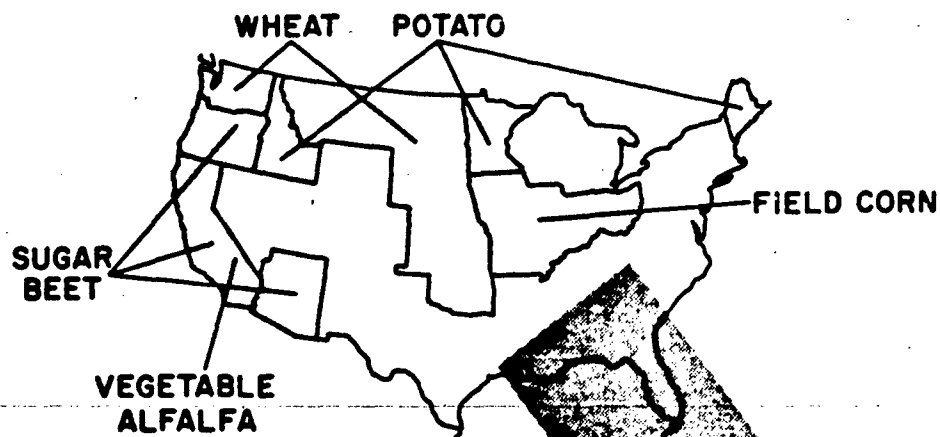
PRODUCTION

SEEDS

DISTRIBUTION

NATIONAL

LOCAL

FARMSTEAD

Chapter XI

SEEDS

A vulnerability study of seed supplies, particularly of commercial sources, was made for a selection of sample crops roughly parallel to the ones studied in the Part I report: wheat and other small grains, potatoes, sugar beets, field corn, alfalfa (and field seeds in general), and vegetable seeds. Since seeds for these types of crops exhibit different production patterns and survival characteristics, each will be discussed separately.

Wheat Seed

Grains like wheat, oats, and barley are self-fertilized and tend to remain uniform in yielding capacity from year to year, so that the farmer can produce his own seed or obtain it locally.[1] In 1958 over 70 percent of the wheat used for seed originated on the farm where it was used.[2] Clearly then, wheat seed would not be a problem; where wheat farms survive so also would the seed stocks, and the tremendous supplies of wheat surpluses would provide an almost unlimited reserve. Vulnerability of wheat seed as an input is nil.

Seed Potatoes

Seed potatoes of good quality would probably be available in sufficient quantity in the first postattack year, except in a few areas. "The majority of growers in the leading potato growing states produce their own seed potatoes, renewing them from outside sources only in occasional years," but, "growers on Long Island, in New Jersey, Virginia, and the

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[1] Wolfe, T. K., and M. A. Kipps, Production of Field Crops, McGraw-Hill Book Co., Inc., New York, 4th Edition, 1953, p. 256; and Davidson, "The Seeds Business--Big and Growing," Agricultural Marketing, April 1957, p. 6.

[2] Field and Seed Crops, Agricultural Marketing Service, U.S. Dept. of Agriculture, Washington, D.C., May 1959.

southern and south central states generally procure seed annually from sources farther north."[1] The five largest North American certified seed producing areas in 1956 in order of importance were: Maine, the Maritime Provinces of Canada, Minnesota, Idaho, and North Dakota.[2] Apparently the northern grown tubers have better yielding ability and are freer from disease,[3] so a continued supply to the southern potato growing areas would be important to postattack potato production.

In general, the potato seed producing areas are located away from attack centers and would not sustain heavy fallout. This remoteness, together with the common practice of planting a crop from seed potatoes grown on the same farm (in 1958, 35 percent of the potato seed was so provided),[4] would indicate a sufficient quantity of seed potatoes post-attack.

Sugar Beet Seed

Sugar beets do not have the close geographical relationship between seed and crop production that wheat and potatoes do. In 1958 three states (Arizona, Oregon, and California) produced 88 percent of the sugar beet seed; Arizona accounting for 37 percent; Oregon, 26 percent; and California, 25 percent. Over the ten-year period 1947-56, these three states produced an average of 90 percent of the total.[5] Sugar beet crop production, however, was widely distributed throughout the western and midwestern states.[6] Although seed can be produced in areas other than where it is normally grown, "seed growing is a technical and highly specialized business carried on largely in regions particularly adapted to the

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1/ Thompson, Homer C., Vegetable Crops, McGraw-Hill Book Co., Inc. New York, 4th Edition, 1949, p. 384.

2/ Agricultural Statistics, 1959, U.S. Dept. of Agriculture, Washington, D.C., 1960, pp. 249-250.

3/ Wolfe and Kipps, op. cit., p. 429.

4/ Agricultural Statistics, 1958, U.S. Dept. of Agriculture, Washington, D.C., 1959, p. 248.

5/ Agricultural Statistics, 1959, U.S. Dept. of Agriculture, Washington, D.C., 1960, p. 81.

6/ Ibid.

production of special crops."[1] A continuing supply of quality seed depends on continuing availability of normal seed production areas.[2]

Cropland used for seeds can contain more radioactive fallout post-attack than cropland used for food crops, because contamination of the plant is not a serious problem if it is not to be eaten. Hence, land that is to be used for non-food crops such as seeds) can be put back into production long before land that is to be used for food crops, provided the exposure level is not too high for farm workers. Also, land with high concentrations of Strontium 90 or other long-lived fission products might be used for seed production even though too contaminated for food production. H plus 1 hr radiation levels of over 10,000 r/hr would be required to deny the use of cropland for seeds within the first three months postattack,[3] while fallout levels of this intensity would be lethal to farmers inhabiting the area ("available shelter" condition assumed).

On the basis of the criteria discussed in Chapters II and IV, an H plus 1 hr radiation level of over 3,000 r/hr can be considered sufficient to prevent workers from returning to postattack production, assuming they are protected by no more than "available shelter." Weighting estimates of harvested cropland availability by the 1958 distribution of sugar beet production in Arizona, Oregon, and California gives the estimates of postattack sugar beet production (as a percentage of preattack production) shown in Table 35.

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[1] Thompson, Vegetable Crops, op. cit., p. 79.
[2] This is perhaps more true of sugar beets than of most seed crops since "sugar beets are biennia' and will not produce seed until the second year or at least until they have passed through a dormant period." See the Part I report, Chapter IV, pp. 8-9.
[3] The statement assumes that re-entry would be done by personnel who received (1) no more than an effective biological dose of 50 roentgens while in confinement and (2) half the "open-field" radiation upon resuming farming. See A Systems Analysis of the Effects of Nuclear Attack on Railroad Transportation in the Continental United States, Stanford Research Institute, April 1960, Table 15, p. 65 and related text.

Table 35

SUGAR BEET SEED PRODUCTION IN FIRST POSTATTACK YEAR

Early 1960's Attacks

Military	98%
Military-Population	93

Late 1960's Attacks

Military	46
Military-Population	35

Field Corn Seed

In 1958, 93.8 percent of the corn acreage in the United States was planted with hybrid seed.[1] Hybrid seed increases the yield of field corn significantly--20 to 30 percent on the average.[1,2] However, crops produced from seed saved from hybrid corn tend to revert to inbred lines,[3] so it is undesirable for the farmer to select his seed corn from his own crop. Rather, he finds it advantageous to buy hybrid seed from the professional breeder.

Hybrid field seed corn is raised by specialized growers throughout much of the corn belt (rather than being restricted to a particular locality as hybrid sweet seed corn is); hence, there is little danger of losing all seed growing areas, and the likelihood of maintaining adequate hybrid seed postattack is good.[4] Even if hybrid seed suppliers were lost, seed production could be maintained at slightly lower levels using home-grown and stored corn surplus supplies.

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[1] Agricultural Statistics, 1959 U.S. Dept. of Agriculture, Washington, D.C., 1960, p. 33.

[2] Wolfe and Kipps, Production of Field Crops, op. cit., p. 58.

[3] Ibid., p. 236.

[4] Opinion based on discussions with officials of the Ferry-Morse Seed Company.

Alfalfa Seed

Most of the alfalfa seed is raised in the arid and semiarid regions of the western United States.[1] The Middle West grows some seed but production there is erratic, varying inversely with the rainfall.[2] In 1958 the most important alfalfa seed producing states were California, Kansas, Utah, and Washington, in that order, with California accounting for 43 percent of the total.[3]

Seeds for crops such as red clover, sweet clover, and lespedeza, show a different production pattern, being primarily located in the same area as their respective crops.[4] Thus, in the aggregate, adequate seed for feed production should be possible postattack.

Seeds for alfalfa and other feed crops are distributed through seed industry channels, where they are cleaned and warehoused for shipment to the farming areas. These channels do not appear particularly vulnerable because stocks are widely scattered and warehouses often located in remote areas.

Vegetable Seed

Vegetable seed growing is a "technical and highly specialized business carried on largely in regions particularly adapted to the production of special crops."[5] California is the most important vegetable seed producing state. However, other areas in the West specialize in the production of certain kinds of vegetable seeds; for example, 80 percent of the hybrid sweet corn seed comes from Canyon County, Idaho.

Ferry-Morse Seed Company, the largest vegetable seed organization in the country, whose practices are typical, grow and handle their seeds in the following manner. The company receives the mature seeds from the seed farmers for cleaning and processing. After being processed, the

1/ Wheeler, W. A., Forage and Pasture Crops, D. Van Nostrand Company, Inc., New York, 1950, p. 266.

2/ Ibid.

3/ Agricultural Statistics, 1959, U.S. Dept. of Agriculture, Washington, D.C., 1960, p. 283.

4/ Wheeler, Forage and Pasture Crops, op. cit., pp. 296, 357, 369; and Agricultural Statistics, 1957, U.S. Dept. of Agriculture, Washington, D.C., 1958, pp. 283-284.

5/ Thompson, Vegetable Crops, op. cit., p. 79.

seeds go to wholesalers throughout the country from where they are distributed to retailers, such as canneries, farm cooperatives, nurseries, and department stores.[1] Seed stocks are usually concentrated at the processing plants rather than at wholesalers' warehouses. In either case, however, the stocks are generally located in cities of less than 50,000.

As with sugar beets, the vulnerability of vegetable seeds is heavily dependent upon the survival of specialized seed farmers and upon the postattack availability of specialized seed growing land. The expected fraction of vegetable seed farmers able to work during the first season after attack is shown in Table 36. The data assume that fallout coverage of farmers is similar to fallout coverage of California cropland.

Table 36

VEGETABLE SEED PRODUCTION IN FIRST POSTATTACK YEAR

	"No Protection" for Farmers	"Available Protection" for Farmers
Early 1960's Attacks		
Military	64%	93%
Military-Population	33	77
Late 1960's Attacks		
Military	34	67
Military-Population	32	37

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[1] Clissold, Edgar J., The Seed Industry, Belman Publishing Co., 1946, p. 18.

The importance of shelter is obvious. The protection of farmers' lives and maintenance of a high level of production capacity would require at least home basement type shelters. "Modified protection" (i.e., improved fallout shelters) would be necessary after the late 1960's military-population attack to ensure at least half of normal seed production. With such "modified protection," the indicated seed production of 37 percent would be increased to over 64 percent.

Losses to vegetable seed production would be offset in part by large inventories of vegetable seed. For most varieties, inventories on June 30 in the hands of dealers and the government normally amount to half a year's production.[1] Moreover, seed quality for future production would be assured by the supplies of foundation and breeder seed that the government maintains at some of the agricultural experiment stations as well as at such specialized installations as the National Seed Storage Laboratory at Fort Collins, Colorado.

With these stocks and adequate shelter for seed farmers, there should be sufficient quantities of vegetable seed postattack to satisfy the demand. The assumption of adequate shelter, however, is critical. Without adequate shelter for seed farmers, demands might still be met from existing seed inventories, but serious problems could be encountered in subsequent years.

Vulnerability Assessment

1. Wheat and Potato Seed

Seed for these crops should prove to be no problem. For the most part these seeds are grown in the same area as that in which the crops are produced. Moreover, in the case of wheat, large surplus stocks are available.

2. Sugar Beet Seed

Sugar beet seed production would sustain the highest losses of all the sample crops, although it is not until the late 1960's attacks that these losses would become extensive. Postattack production following

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[1] Agricultural Statistics, 1959, U.S. Dept. of Agriculture, Washington, D.C., 1960, pp. 289-290.

the late 1960's military attack could be expected to drop to 46 percent of preattack levels, and following the military-population attack it could fall to less than 35 percent.

3. Field Corn Seed

For best yield, field corn should be grown from hybrid seed. Adequate hybrid corn seed could probably be provided postattack; where it could not, corn could still be grown from seed corn selected by the farmer from his own crop or from surplus stocks, albeit at yields reduced perhaps 25 percent.

4. Alfalfa Seed

Alfalfa seed, like sugar beet seed, is produced in specialized areas. However, alfalfa seed areas are more dispersed, and therefore alfalfa seed production should not sustain as heavy losses. Furthermore, other field seeds show even less geographical concentration than alfalfa, so that in the aggregate, field seeds are not particularly vulnerable.

5. Vegetable Seed

Vegetable seed vulnerability is tied closely to the amount of fallout protection provided to the seed growing farmers. However, even in the absence of adequate protection, first-year requirements could probably still be met by depleting existing stocks to make up for production deficiencies.

Vulnerability Summary

Although certain seed crops can be severely affected by nuclear attacks because of the concentration of production in relatively small areas and the requirement for particular skills, seed vulnerability does not in general appear to be greatly different from vulnerability of all crops. Certain factors even favor the availability of seeds in a postattack environment, such as the normal existence of widely dispersed seed stocks and the relatively high tolerances for seed crop production on contaminated land. Therefore, although it might be necessary to adopt some cultural changes or to use inferior seed in the case of vulnerable crops, it is likely that seed supplies would be adequate for sowing available cropland in the first postattack year.

INPUTS
LAND
MANPOWER
PETROLEUM FUELS
EQUIPMENT
ELECTRIC POWER
IRRIGATION WATER
SOIL NUTRIENTS
PESTICIDES
SEEDS

PREATTACK PRODUCTION

POSTATTACK PRODUCTION

FOOD
SUPPLY

PRODUCTION LOSS DUE TO LOSS OF INPUTS

FOOD
LOSSES

Chapter XII

POSTATTACK PRODUCTION

Summary of Input Availabilities

The preceding chapters have been concerned with estimating the postattack availabilities of the more critical agricultural inputs. Table 37 summarizes these estimates.

The aggregate availability and total agricultural output can be estimated by applying the equation given in Chapter II:

$$Q = min(L,Mgt) \cdot f(N) \cdot f(P) \cdot f(K) \cdot f(Pe) \cdot f(E) \cdot f(F+M) \cdot f(S,W,Eq, Mnr,Lim)$$

(where Q = output; L = cropland or livestock; Mgt = management; N = nitrogen fertilizer; P = phosphate fertilizer; K = potash fertilizer; Pe = pesticides; E = electric power; F+M = fuel + farm manpower; S = commercial seeds; W = water; Eq = equipment; Mnr = manure; Lim = liming materials).

Since the last five inputs are expected to be in sufficient supply relative to other inputs, they can be dropped from the expression.[1] The simplified function then is:

$$Q = min(L,Mgt) \cdot f(N) \cdot f(P) \cdot f(K) \cdot f(Pe) \cdot f(E) \cdot f(F+M)$$

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[1] As is indicated in Table 37 and was seen in their respective chapters, farm equipment and liming materials show good postattack survival relative to their requirements. The situation for seeds, although not so clear, is probably adequate because large, dispersed supplies of seeds exist for most crops, and crops which could not be fully seeded by surviving supplies could be replaced by other crops until new seed supplies could be grown. Availability of irrigation water is closely tied to availability of electric power, and is considered with that function. Manure production and use is directly related to livestock production, and therefore is not evaluated separately.

Table 37

GROSS INPUT AVAILABILITIES DURING FIRST POSTATTACK YEAR
AS PERCENTAGES OF PREATTACK TOTALS

	Early 1960's Attacks		Late 1960's Attacks	
	Military	Military-Population	Military	Military-Population
Land (Cropland)1/	96%	86%	41%	27%
Land (Livestock)2/	86	67	34	19
Manpower (Farm Managers)3/	96	93	76	64
Manpower (Farm Labor)3a/	147	139	114	93
Fuel (Gasoline)4/	100	85	82	41
Equipment (Agricultural)	5/	5/	5/	5/
Electric Power	100	60	80	30
Irrigation Water	5a/	5a/	5a/	5a/
Soil Nutrients				
Manure	5b/	5b/	5b/	5b/
Nitrogen	97	82	66	32
Phosphate	25	25	15	15
Potash	100	100	0	0
Liming materials	5/	5/	5/	5/
Pesticides	100	40	70	20
Seeds	5/	5/	5/	5/

1/ Percent of harvested cropland receiving less than 1,000 r/hr at H plus 1 hr.

2/ Combined average of animals given shelter (permissible H plus 1 hr level of 1,000 r/hr) and those without shelter (permissible H plus 1 hr level of 100 r/hr at H plus 1).

3/ With "available protection" (protection factor = 20). Includes resident managers and farmers.

3a/ With "available protection." Includes potential farm workers, including farm residents not normally working on farms as a percentage of the normal number of farm workers.

4/ Includes fuel stored on farms and in rural areas.

5/ Adequate to provide normal amounts relative to other inputs.

5a/ Proportional to electric power availability.

5b/ Proportional to livestock availability.

The production function can be applied to crops and livestock in combination (as was done in the Part I report), or it can be applied separately. In this report it is applied separately so that the different variables involved in crop and livestock production can be explicitly analyzed. Crops are considered first.

Postattack Crop Production

First, the minimum of cropland and management resources is determined. From Table 37, the minimum of the two is seen to be cropland for all four attacks (e.g., the limiting constraint in the early 1960's military attack is 0.96).

Next, availabilities of the other inputs in the simplified production function are calculated relative to the availability of cropland. These availabilities are shown in Table 38 (e.g., farm labor is 147 percent of normal in the early 1960's military attack, or 153 percent relative to the 0.96). Availabilities of inputs in quantities greater than some maximum value (200 percent of normal for fertilizers and labor, 100 percent for all other inputs) are ignored.

Third, productivities for each of the necessary terms in the aggregate response function are obtained by comparing the availabilities in Table 38 with the crop response functions in Figure 2. For example, phosphate availability is 35 percent of normal after the early 1960's military attack. This corresponds in Figure 2 to a productivity fraction of about 0.96. Fractions for other inputs in this case may be seen to be:

Limiting Constraint (Cropland)	0.96
Farm Labor + Fuel	1.06
Electric Power	1.00
Nitrogen Fertilizer	1.00
Phosphate Fertilizer	0.96
Potash Fertilizer	1.00
Pesticides	1.00

When these fractions are multiplied together, the product, Total Crop Output, is seen to be equal to 0.98. By this means, estimates are obtained of potential national crop output in the first year following all hypothetical attacks. These estimates are given in Table 39.

Table 38

CROP INPUT AVAILABILITIES IN FIRST POSTATTACK YEAR

	Early 1960's Attacks		Late 1960's Attacks	
	Military	Military-Population	Military	Military-Population
Limiting Constraint (Cropland)	.96	.86	.41	.27
Other Inputs Relative to Availability of Limiting Constraint:				
Farm Labor[1]	153%	162%	>200%	>200%
Fuel (Gasoline)	>100	99	>100	>100
Electric Power[2]	>100	90	>100	>100
Nitrogen Fertilizer[3]	108	102	175	130
Phosphate Fertilizer[4]	35	40	50	76
Potash Fertilizer[5]	116	130	0	0
Pesticides	>100	47	>100	75

[1] Includes available farm residents normally employed in other than agricultural work.

[2] Assumes that availability may be increased 30 percent by rationing and use of excess capacity where needed.

[3] Assumes that excess preattack capacity (7 percent in early 1960's, 10 percent in late 1960's) is used.

[4] Assumes that 20 percent phosphorus normally exported is diverted to domestic fertilizer use, providing 75 percent of postattack phosphorus production for fertilizers.

[5] Assumes that excess preattack capacity (12 percent in early 1960's) is used.

Table 39

CROP PRODUCTION IN FIRST POSTATTACK YEAR
ALL CROPS EXCEPT ANIMAL FEED CROPS
(Percent of Preattack Production)

Early 1960's Attacks

Military	98%
Military-Population	74

Late 1960's Attacks

Military	41
Military-Population	25

The above estimates are made under the assumption that farmers would generally continue to produce the same products as before attack but would modify their cultural practices to adapt as well as possible to shortage conditions. The extent of central planning is indicated in the footnotes to Table 38. If the re-allocation and rationing conditions specified in Table 38 were not applied, total crop output would be about 10 percent less than indicated (92 percent, 67 percent, 35 percent, and 22 percent, respectively, for the four attacks).

The output estimates given above assume that only cropland having H + 1 hr radiation of less than 1,000 r/hr is suitable for crop production and that farm manpower is protected by "available shelter." Crop production under variants of this assumption with different land contamination values has been considered in Figure 18. Production under different types of fallout protection for manpower is shown in Figure 19.

Examination of Figure 18 reveals that the assumption regarding cropland contamination is a critical one. Present indications are that the cropland tolerance assumption of 1,000 r/hr at H + 1 hr is more accurate than the 300 or 3,000 r/hr levels. However, there has been insufficient study of this problem to be able to specify a contamination tolerance level with confidence. In view of the sensitivity of the results to the level selected, greater study of this question seems warranted.

FIG. 18
POSTATTACK CROP PRODUCTION FOR THREE ASSUMED CROP
RADIATION TOLERANCE LEVELS
(MANPOWER PROTECTED UNDER "AVAILABLE SHELTER" CONDITION)

PERCENT OF PREATTACK PRODUCTION

| | 0 | 20 | 40 | 60 | 80 | 100 |

EARLY 1960s MILITARY ATTACK
97
98
100

EARLY 1960s MIL.-POP. ATTACK
70
74
78

LATE 1960s MILITARY ATTACK
27
41
67

LATE 1960s MIL.-POP. ATTACK
14
23
42

300 r/hr (AT H+1 hr)
1000 r/hr (AT H+1 hr)
3000 r/hr (AT H+1 hr)

190

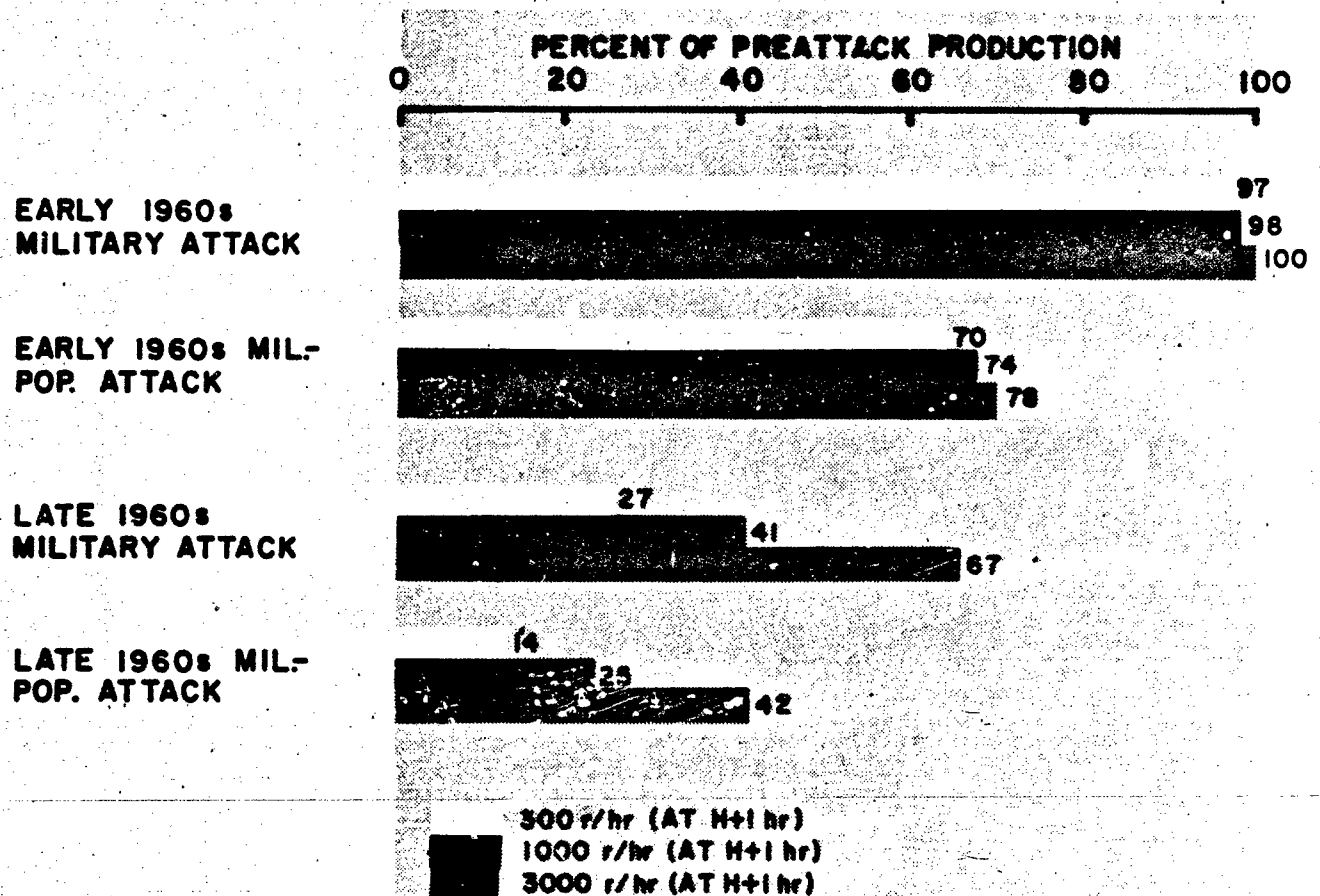FIG. 19
POSTATTACK CROP PRODUCTION FOR TWO PERSONNEL
SHELTER CONDITIONS (1000 r/hr CROP TOLERANCE LEVEL)

PERCENT OF PREATTACK

| | 0 | 20 | 40 | 60 | 80 | 100 |

EARLY 1960s
MILITARY ATTACK
92
98

EARLY 1960s MIL.-
POP. ATTACK
84
74

LATE 1960s
MILITARY ATTACK
24
41

LATE 1960s MIL.-
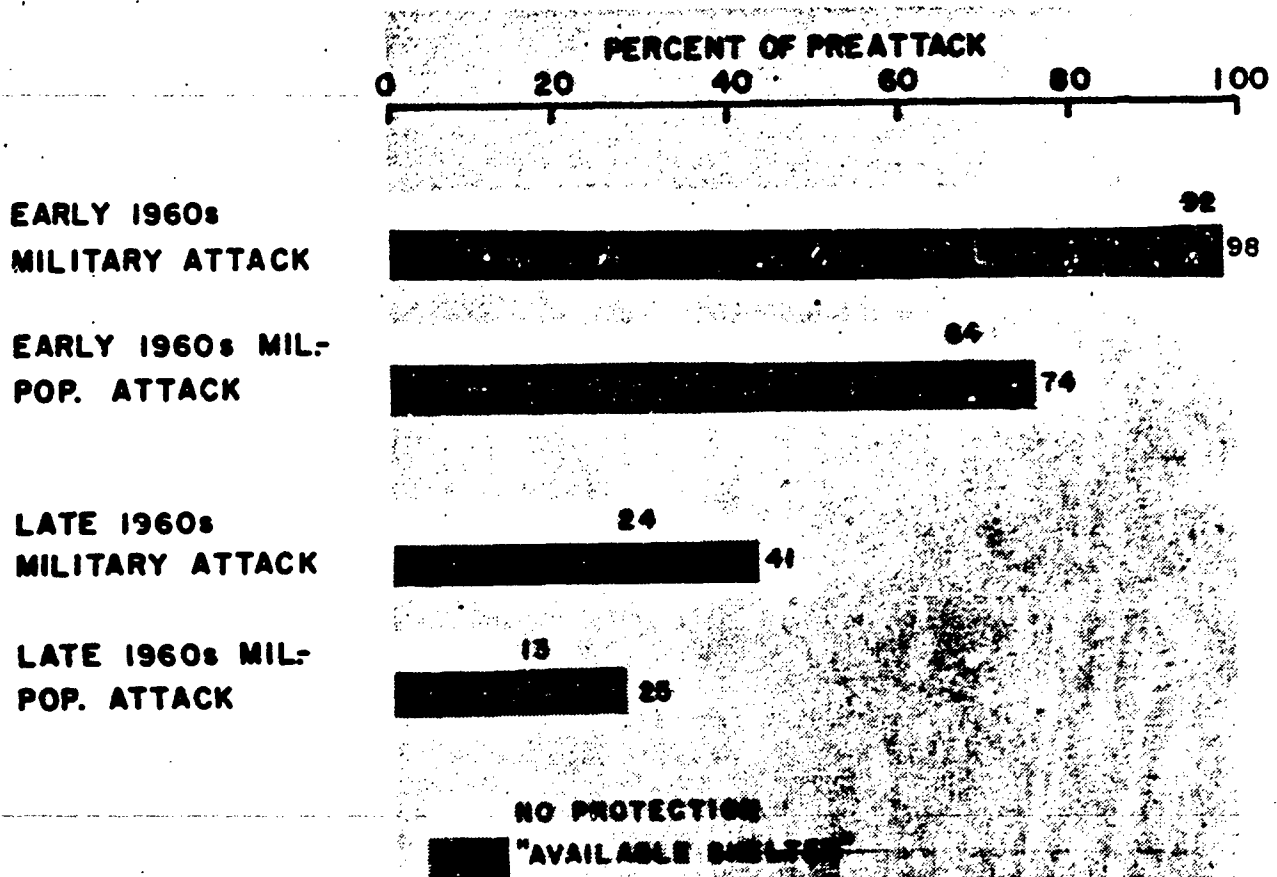POP. ATTACK
13
25

NO PROTECTION
"AVAILABLE SHELTER"

Figure 19 shows that the lack of fallout protection for farmers could reduce postattack farm production by almost half under the heavier attacks.

Postattack Livestock Production

The availability and productivity of livestock are estimated in the same manner as for crops. Input availabilities are shown in Table 40 on the following page, productivity functions in Figure 3, and the resultant postattack livestock production in Table 41, below.

Livestock output is little improved by the reallocations and rationing listed in the footnotes of Table 40; postattack production without such reallocation and rationing would be only about 3 percent less than shown in Table 41.

The indicated proportion of normal livestock production is about one-eighth to one-quarter less than the surviving fraction of crops indicated in Table 39. However, these differences are largely dependent upon assumptions of vulnerability to fallout.

Table 41

LIVESTOCK PRODUCTION IN FIRST POSTATTACK YEAR
(Percent of Preattack Production)

Early 1960's Attacks

Military	83%
Military-Population	63

Late 1960's Attacks

Military	33
Military-Population	19

The livestock estimates assume that all sheltered animals in areas receiving H + 1 hr radiation of less than 1,000 r/hr and all unsheltered livestock in areas where fallout is less than 100 r/hr survive, and that farm management is protected by "available shelter" (i.e., basements or

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Table 40

LIVESTOCK INPUT AVAILABILITIES IN FIRST POSTATTACK YEAR

	Early 1960's Attacks		Late 1960's Attacks	
	Military	Military-Population	Military	Military-Population
Limiting Constraint (Livestock)	.86	.67	.34	.19
Other Inputs Relative to Availability of Limiting Constraint:				
Farm Labor[1]/	170%	>200%	>200%	>200%
Fuel (Gasoline)	>100	>100	>100	>100
Electric Power[2]/	>100	100	>100	>100
Nitrogen Fertilizer[3]/	121	130	>200	190
Phosphate Fertilizer[4]/	39	50	60	107
Potash Fertilizer[5]/	130	170	0	0
Pesticides	>100	60	>100	>100

1/ Includes available farm residents normally employed in other than agricultural work.

2/ Assumes that availability may be increased by more than 10 percent by rationing and use of excess capacity where needed.

3/ Assumes that excess preattack capacity (7 percent in early 1960's, 10 percent in late 1960's) is used.

4/ Assumes that 20 percent of phosphorus normally exported is diverted to domestic fertilizer use, providing 75 percent of postattack phosphorus production for fertilizers.

5/ Assumes that excess preattack capacity (12 percent in early 1960's) is used.

similar fallout shelters). The effects of varying the livestock radiation tolerance levels and the farmer (and farm laborer) shelter conditions are shown in Figures 20 and 21.

The results are similar to those obtained for crops. Production is quite sensitive to the radiation level that would be damaging to livestock. Also, the lack of fallout protection for farm manpower would result in a decided reduction in livestock output following either of the late 1960's attacks, because farm workers would then be more vulnerable than the livestock. Although these results are highly dependent on the assumptions of the model, they do indicate the dependence of production on adequate and balanced inputs. Since output is particularly sensitive to the livestock radiation assumptions, it is obviously desirable to be able to specify these levels with confidence. Unfortunately, this is not currently possible (see discussion in Chapter III).

Postattack Aggregate Agricultural Output

By assigning what appears to be the most appropriate cropland contamination level (1,000 r/hr at H + 1 hr), and livestock survival level (100 and 1,000 r/hr at H + 1 hr for unsheltered and sheltered animals, respectively), an aggregate measure of crop and livestock output postattack can be obtained. Aggregate production can be measured according to relative monetary farm values of food crops and livestock in 1958 by weighting the crop and livestock output by .30 and .70, respectively (other measures are discussed in Chapters II and XIII of the Part I report and in Chapter XIII of this report).

The seriousness of aggregate agricultural production losses can best be evaluated if they are compared with the proportion of the national population that is lost. Figure 22 shows these population-vs-output relationships for two assumed population shelter protection conditions.

With the single exception of the early 1960's military-population attack, population survival exceeds postattack agricultural output (expressed as percentages of preattack population and farm production). This means that food production could well be a problem--perhaps a serious problem--unless measures were taken to adapt to the postattack situation.

FIG. 20
POSTATTACK LIVESTOCK PRODUCTION FOR TWO ASSUMED
LIVESTOCK RADIATION TOLERANCE LEVELS (MANPOWER
PROTECTED UNDER "AVAILABLE SHELTER" CONDITION)

PERCENT OF PREATTACK PRODUCTION

EARLY 1960s
MILITARY ATTACK — 83 / 91

EARLY 1960s MIL.-
POP. ATTACK — 63 / 74

LATE 1960s
MILITARY ATTACK — 33 / 46

LATE 1960s MIL.-
POP. ATTACK — 19 / 32

100 r/hr WITHOUT SHELTER
1000 r/hr WITH SHELTER
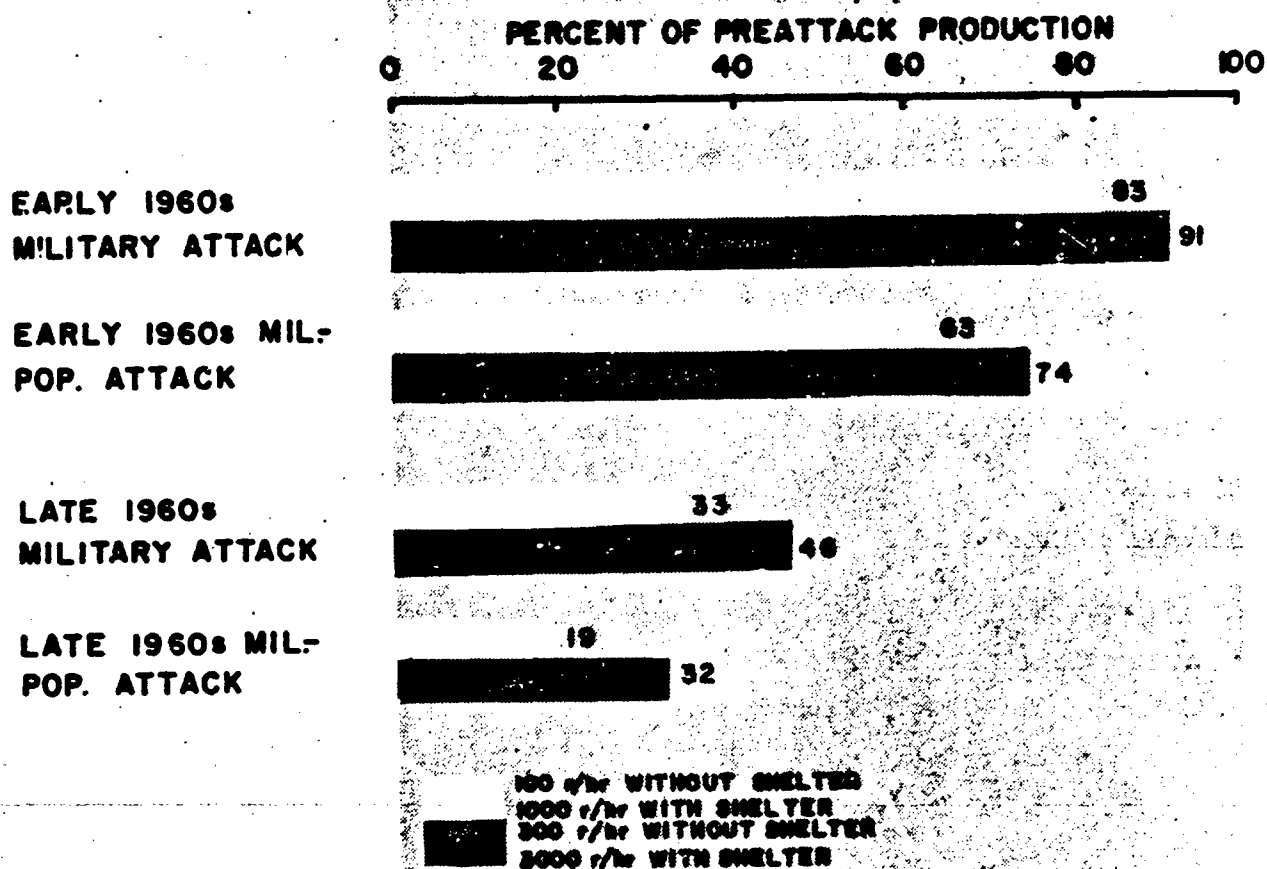300 r/hr WITHOUT SHELTER
3000 r/hr WITH SHELTER

FIG. 21
POSTATTACK LIVESTOCK PRODUCTION FOR TWO PERSONNEL
SHELTER CONDITIONS (100 and 1000 r/hr LIVESTOCK TOLERANCE LEVELS)

PERCENT OF PREATTACK

0   20   40   60   80   100

EARLY 1960s
MILITARY ATTACK   83
                         84

EARLY 1960s MIL.-   82
POP. ATTACK   63

LATE 1960s   25
MILITARY ATTACK   32

LATE 1960s MIL.-   13
POP. ATTACK   19
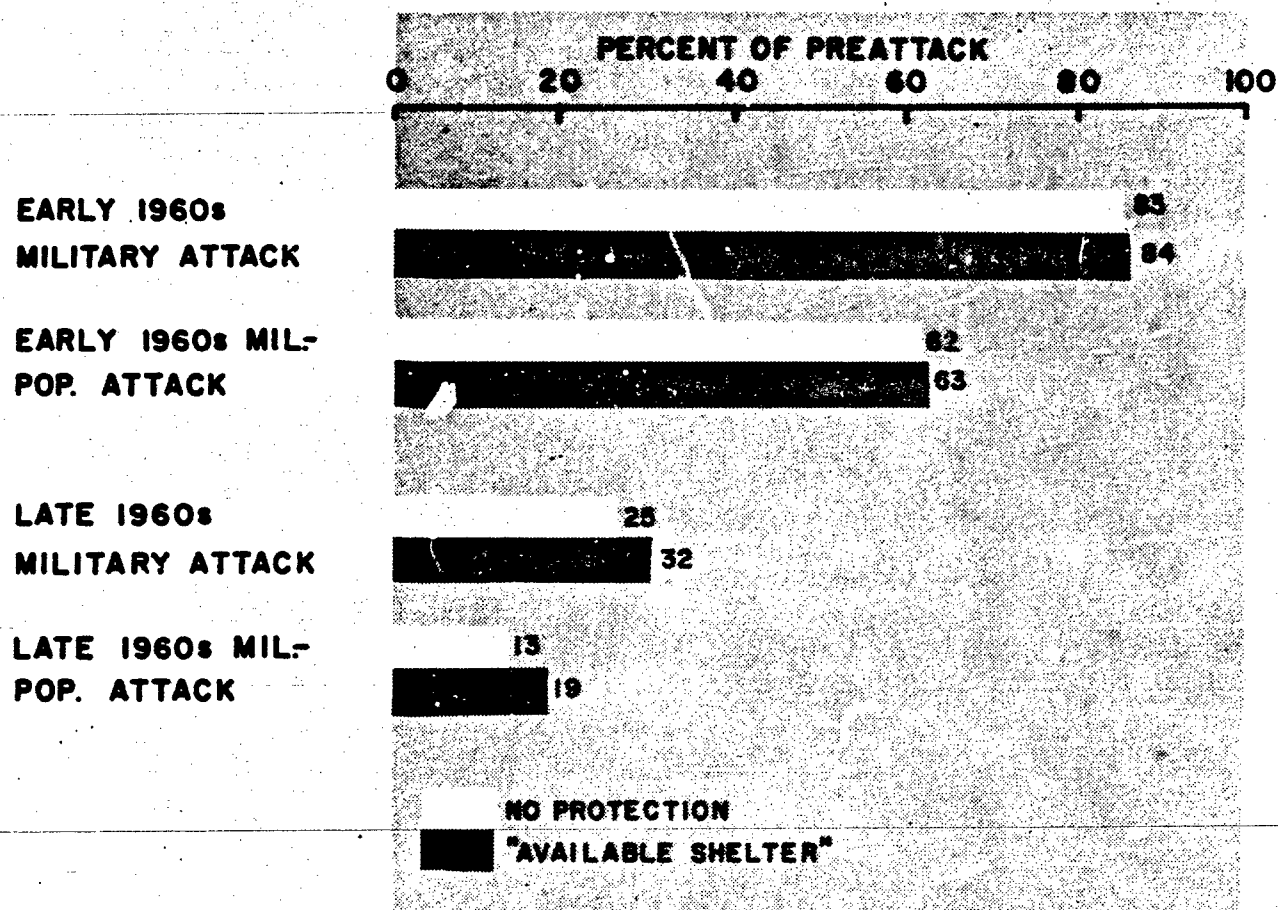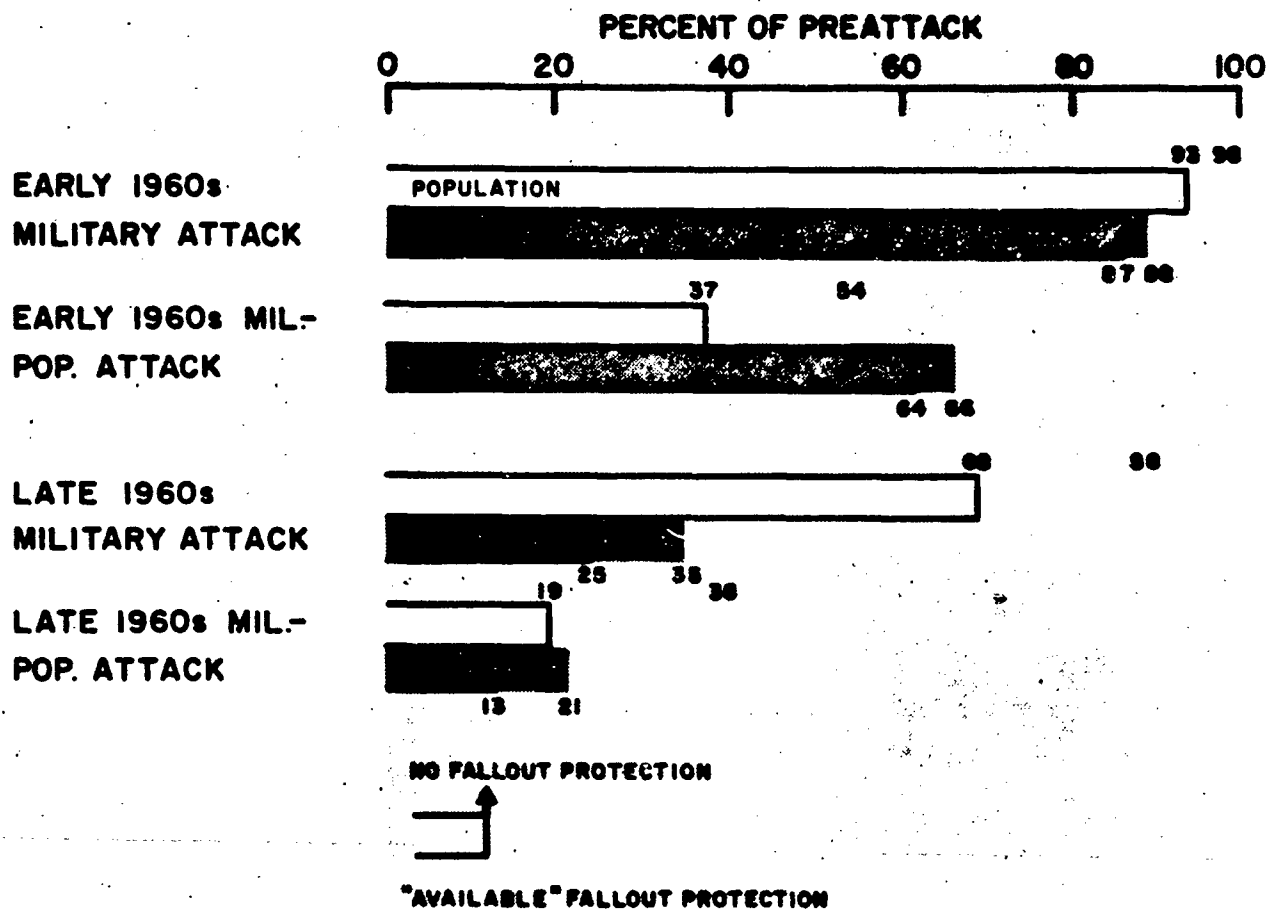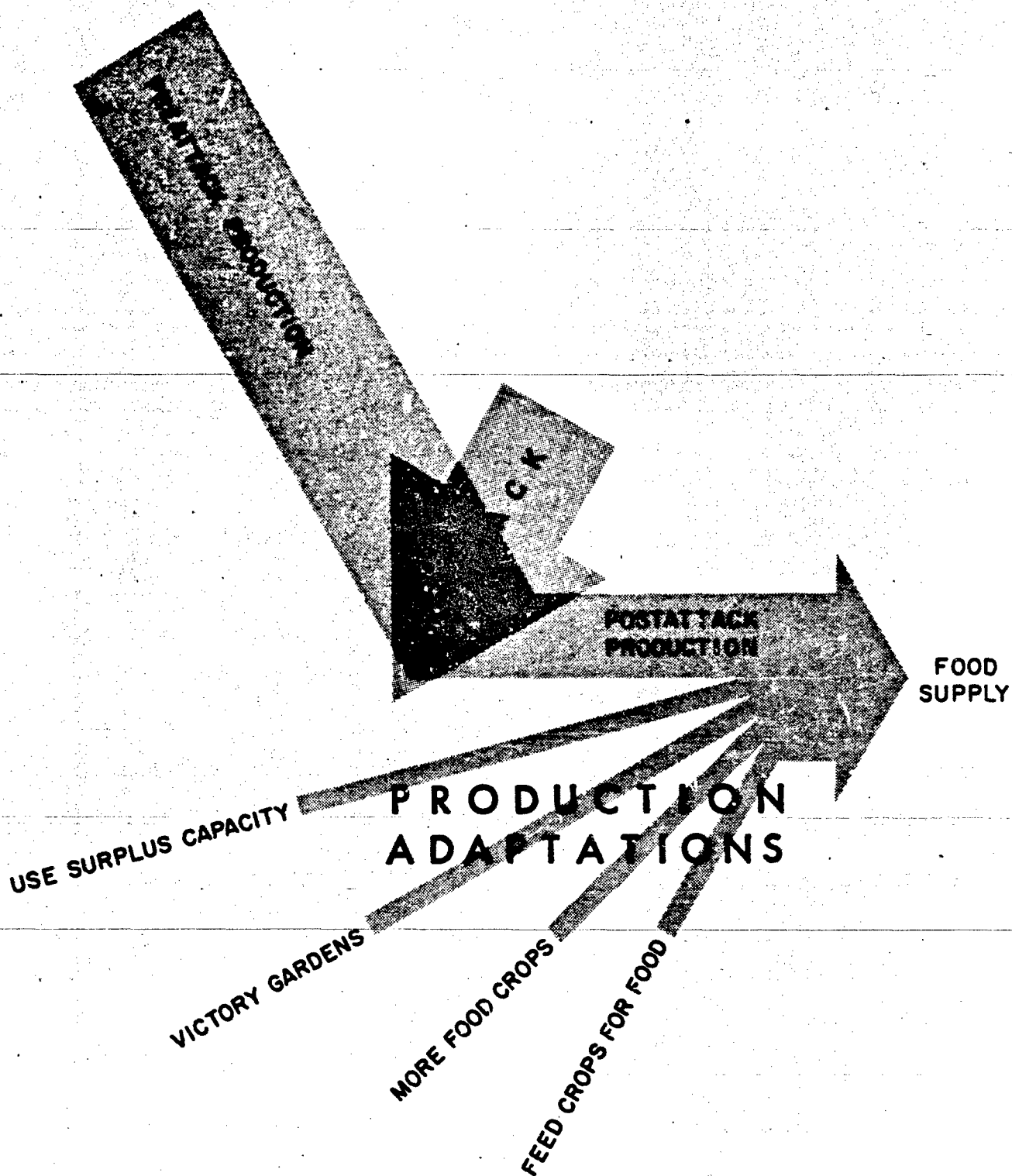
☐ NO PROTECTION
■ "AVAILABLE SHELTER"

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FIG. 22
POSTATTACK POPULATION SURVIVAL AND AGRICULTURAL
PRODUCTION FOR TWO PERSONNEL SHELTER CONDITIONS

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Chapter XIII

PRODUCTION ADAPTATIONS

Methods of Improving Food Production

Nine adaptations to increase postattack agricultural production were suggested and their potentialities were discussed in Part I of this study.[1] Some of these adaptations have also been related to the possible postattack situation in the previous section of the present report. These include increasing the use of manpower, increasing the rates of fertilizer application, and assigning fuel stocks to the more efficient farms, as well as giving priority use of electric power to farmers when this input is in short supply. Other possible adaptations mentioned in Part I are:

1. Utilizing surplus agricultural capacity

2. Encouraging victory garden home food production

3. Replacing production of non-food crops with production of food crops

4. Diverting feed grain consumption from livestock to the population

Consideration of these latter four possibilities in the light of possible postattack conditions requires a further analysis based on the data generated in this report. A discussion of each adaptation and a summary of the total possibilities for increasing production are added below.

1. Utilizing surplus agricultural capacity involves two adjustments: putting available land retired under the soil bank conservation reserve back into production, and making allowance for normal excess production of food crops.

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[1] Part I Report, Chapter XIII.

In 1959 there were 22.4 million acres in soil bank status, or about 14.5 percent of the number of acres of cropland used by the principal food crops for the year 1958.[1] Since large amounts of hay and pasture land are included in the soil bank, and since there is a tendency for marginal land to be retired, the additional cropland availability would not exceed 4 to 5 percent on a productivity basis.[2] Improved production practices on land already in use could well double this increase, adding a total of perhaps 9 percent to the production of existing farmland.[3]

The amount that normal excesses of food crop production could contribute to the over-all food stocks is difficult to estimate because this surplus varies considerably. If the five-year period 1954-58 is representative, excess production of food grains, fruits, vegetables, and sugar crops would average (on an equivalent-farm-value basis) about $250 million a year.[4] If the excess of exports (including deliveries under the USDA export program) over imports is considered to represent additional excess capacity, then to this $250 million may be added

1/   The 59 principal crops in 1958 accounted for 330 million acres, of which 137 million acres were in four feed grains (corn, oats, barley, and sorghum) and 41 million acres were in non-food crops (flaxseed, cotton, soybeans, and tobacco). Food crop acreage can then be taken to be about 152 million acres. Agricultural Statistics: 1959, U.S. Dept. of Agriculture, Washington, D.C., 1960, pp. 454, 455, 528.

2/   A 10-percent reduction of grain capacity alone under average conditions might require a soil bank of 35-40 million acres of crop and pasture land. See Paulson, Arnold, Earl O. Heady, Alvin C. Egbert, Ray Brokken, and Melvin Skold, Retire the Excess Capacity?, manuscript under preparation.

3/   Rogers, Robert O., and Glenn T. Barton, Our Farm Production Potential, 1975, Agricultural Information Bulletin No. 233, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, D.C., 1960, p. 14. A small error is introduced by not recomputing the availability of each input relative to the additional amount of land in soil bank status. However, most of these inputs would be relatively more available than cropland, and individual farmers would find it relatively easy to expand their production if they were able to farm at all.

4/   Supplement for 1956 to Measuring the Supply and Utilization of Farm Commodities, Agricultural Handbook No. 91, Agricultural Marketing Service, U.S. Dept. of Agriculture, Washington, D.C., October 1957, p. 44. Supplement for 1958 to Measuring the Supply and Utilization of Farm Commodities, Agricultural Handbook No. 91, Agricultural Marketing Service, U.S. Dept. of Agriculture, Washington, D.C., September 1959, p. 18.

$880 million[1]/ to yield a total surplus of $1,130 million. This total amounts to 14 percent of the 1958 net food crop production,[2]/ or 16 percent of net domestic food use.[3]/

2. Encouraging victory garden home food production could perhaps increase food crops by 3 percent of the indicated fraction of population survival, and livestock by 3 percent of the estimated livestock output.[4]/

3. The effect of replacing non-food crops with food crops can be estimated on the same basis as the acreage relationships given above in evaluating soil bank effects. In 1959 flaxseed, cotton, soybeans, and tobacco were planted on 41 million acres, as compared with 152 million acres for food crops. Utilizing one-half of this non-food crop acreage for food crops would add 13 percent more land for food crop production. After allowing for losses in productivity because of changes in practices, an increase in crop production postattack of 9 percent of indicated levels might be expected.

In summary, the effects of these three adaptations would be:

Adaptation	Percentage Increase in Indicated Postattack Output	
	Crops	Livestock
1. Utilize surplus capacity		
a. Soil bank	9%	0
b. Storage and export surplus	16	0
2. Raise victory gardens	5/	3%
3. Use non-food cropland for food crops	9	0

1/ 1954-58 average, Ibid, p. 38 in 1956 Supplement and p. 16 in 1958 Supplement.

2/ Part I Report, Table I.

3/ Considering the whole of the excess as food crops is probably realistic since no significant amounts of livestock products go into stockpiles or are exported.

4/ See Part I Report, Chapter XI.

5/ The increase would amount to .03 times the percentage of surviving population.

The combination of these effects would yield the domestic food crop and livestock availabilities given in Table 42. Crop production could be maintained at much higher levels than livestock production, but the aggregate (based on monetary value) is less than preattack output for all except the smallest attack.

Table 42

CROP AND LIVESTOCK PRODUCTION IN FIRST POSTATTACK YEAR,
USING SURPLUS CAPACITY, VICTORY GARDEN, AND NON-FOOD TO FOOD
CROP ADAPTATIONS
(Percent of Preattack Production)

	Postattack Crop Production		Postattack Livestock Production	
	With "Available Protection"	With "No Protection"	With "Available Protection"	With "No Protection"
Early 1960's Attacks				
Military	133%	126%	86%	86%
Military-Population	101	87	65	64
Late 1960's Attacks				
Military	58	34	34	26
Military-Population	35	18	20	13

However, because monetary value inadequately weights the basic nutritional value of crops, it is worthwhile to examine the effects of using food nutrients as the weighting basis. On a monetary value basis, the weights assigned have been .30 for food crops and .70 for livestock. On a food energy basis, the weights are 0.6 for food crops and 0.4 for livestock.[1] Table 43 indicates total production by both food and monetary value.

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[1] Supplement for 1958 to Consumption of Food in the United States 1909-1952, Agricultural Handbook No. 62, Agricultural Marketing Service, U.S. Dept. of Agriculture, Washington, D.C., September 1959, p. 15.

Table 43

FOOD PRODUCTION, WITH THREE ADAPTATIONS, UNDER
"AVAILABLE PROTECTION" CONDITIONS, IN FIRST POSTATTACK YEAR
(Percent of Preattack)

	Monetary Basis	Food Energy Basis
Early 1960's Attacks		
Military	100%	114%
Military-Population	75	87
Late 1960's Attacks		
Military	41	49
Military-Population	25	29

The change in weighting procedure reduces but does not eliminate the late 1960's postattack shortage of food production. It therefore becomes relevant to consider the effect of introducing a major modification in the pattern of postattack agricultural production.

4. Diverting feed grain consumption from livestock to the population would increase food efficiency by supplying feeds such as corn directly to pecple as food rather than going through the metabolically inefficient process of raising livestock. The influence of this diversion is to increase food crop production by 70 percent[1] and decrease livestock production by 50 percent.[2]

1/ On the basis of preattack relations, this adaptation would divert 137 million acres from feed to food purposes. Already in food crop production would be 152 million acres (normally) plus 22 million acres (soil bank) plus 20 million acres (shift from non-food to food crops), or a total of 194 million acres.

2/ Under normal (1958) conditions, feed grains account for about $9.7 billion of the $19.8 billion of livestock production, or roughly 50 percent. See Part I Report, Chapter XIII.

Total postattack food energy production as increased by this meature and all the preceding adaptations is shown in Figure 23 at the end of the chapter. First-year agricultural productive capacity is compared in the figure with food requirements for two preparedness conditions (both resources and requirements are expressed in terms of the percentage of normal domestic food requirements). Postattack food requirements represent the percentage of 1960-65 U.S. population that would be expected to survive the four hypothetical attacks.

The adaptations are seen to almost double food production over the percentage indicated in Figure 22. Potential productivity with all adaptations would be relatively adequate for the surviving population except in the late 1960's military attack. Variation in the degree of fallout shelter would have little effect on the balance between food production and people, because a variation in losses of farm workers is accompanied by a similar variation in total population losses. From the viewpoint of providing food for the population, the worst condition examined (late 1960's military attack, no use of fallout shelters) showed production equal to over 60 percent of the per capita first-year food requirements. With the existence of stored stockpiles and the possibility of reducing per capita civilian needs, such productivity appears to be sufficient for minimum needs in a postattack environment.

Unexplored Factors

Extension of this analysis into the period beyond one year postattack has not been attempted, because the outlook in that later period would be greatly dependent on the success of survival and recovery actions. The food situation after the first year would be aggravated to the extent that reserves of food and of agricultural input resources become exhausted and cumulative effects of shortages (such as in fertilizers and pesticides) become more significant. On the other hand, the food situation would be alleviated to the extent that agricultural activities and supplies of inputs are re-established and adjustments (such as substitution of hand milkers for milking machines and of home gardens for purchased produce) are made to accommodate continuing shortages. In toto, the food supply situation would probably improve after the first year unless international and/or internal conditions remained greatly unsettled.

Precisely what effect attack timing might have on farm production has not been evaluated. Clearly, if an attack were to occur in September there would be a different problem of providing inputs to agriculture in the following crop year than if the attack came in March. However, there

are compensating factors. If the attack were to occur in the fall when stocks of agricultural inputs are normally at their lows, the economy would have a period of some 6 months in which to recover and begin supplying agriculture with the required inputs. If the attack were to occur in the spring, stocks of many of the agricultural inputs would already have been partly built up, and these could be initially drawn upon while recovery programs got under way. Moreover, if, for example, fertilizers were unavailable early in the season, later applications on some crops could partly compensate for the early deficiency.

A similar environmental problem which has not been investigated is the effect of nuclear blast, heat, fires, fallout, induced radiation, and other phenomena on plant and animal ecology. Undiscovered effects, such as biological concentration of radioactive products, disruptions of the balance of nature because of unequal vulnerability of species, topological changes caused by blast or fires, and climatic changes caused by airborne particles, could severely limit production. Current beliefs are that environmental influences would not greatly modify the conclusions of this study, but conclusive data for verification of these beliefs are not presently available.

Another uncertainty is the effect of nuclear attack on trade and the general economy. Extensive disruptions could be expected unless a well-developed recovery plan were worked out in advance and coordinated with national, state, and local officials directing the recovery effort. This study assumes that the industrial inputs, especially fuel, fertilizers, and pesticides, can be provided to the extent that surviving capacity allows. Accomplishing this entails not only distributing the final product to the farm but, fully as important, supplying the manufacturing plants that produce these commodities with manpower, equipment, parts, and materials.

Beyond this, it is further necessary to provide distribution facilities for moving the product of agriculture away from the farms into the hands of the surviving population. This involves not only transportation but, in some cases, food processing as well. Although it has not been possible to analyze this aspect in this study, the problem of postattack food supplies is incomplete until such an evaluation is performed. In general, it appears that there should be adequate railroad transportation

available postattack.[1] Water, pipeline, and truck transportation prob-
ably have equally good or better survival characteristics. Hence, the
distribution problem is not so much one of physical facilities as of
organization.

Finally, the surplus stocks of some agricultural commodities now
stored by the federal government are seen to be the most important single
"controllable" factor in the early postattack food situation. Alternative
policies and procedures for use of these stocks have been suggested here,
but a definitive evaluation of possibilities for their use will require
much more detailed study. A small amount of future planning in this area
can perhaps yield more results for postattack recovery than a comparable
amount of activity in any other agricultural effort.

1/   A System Analysis of the Effects of Nuclear Attack on Railroad Trans-
     portation in the Continental United States, Stanford Research Institute,
     April 1960.

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FIG. 23
POSTATTACK POPULATION SURVIVAL AND AGRICULTURAL PRODUCTION INCLUDING EFFECTS OF ALL ADAPTATIONS FOR TWO PERSONNEL SHELTER CONDITIONS

PERCENT OF PREATTACK